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A COAXIAL EXTRUSION CONVERSION CONCEPT FOR POLYMERIC FLAT PLATE SOLAR COLLECTORS

Final Technical Report, September 30, 1978—December 31, 1979

By
Richard O Rhodes
Nicholas J. Chapman
Kwang C. Chao
Kenneth F. Sorenson

January 1980

Work Performed Under Contract No. AC03-78CS32241

FAFCO Incorporated
Menlo Park, California

U.S. Department of Energy

Solar Energy

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FAFCO INCORPORATED
235 Constitution Drive
Menlo Park, California 94025

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ABSTRACT

This study investigated materials and processes for fundamental improvements in flat-plate solar collector cost and performance. The goal was to develop a process for direct conversion of inexpensive raw materials into a completed solar collector unit, without labor intensive assembly operations. It was thought that materials carefully matched to the process and 'end-use' environment would substantially reduce collector costs, as compared to conventional industry practice.

The project studied the feasibility of a cost-effective, glazed solar collector, with low labor input, utilizing a coaxial extrusion of compatible polymeric materials.

This study evaluated all considered materials for the desired application. In addition, there was a trial extrusion of the leading candidate glazing and absorber materials, which resulted in successfully performing a coaxial extrusion of one cell.

At the time the study was conducted, there were no materials available that met the necessary requirements for the specified utilization. It was recommended that, if potentially compatible materials become available, further investigation into the suitability of those materials be researched. Then, if a suitable material was found, proceeding into Phase II would be recommended. Phase II, at that point, would include the following goals:

- o Design and evaluate materials conversion processes for mass production of solar collectors from the materials chosen in Phase I.
- o Build and evaluate a prototype collector.
- o Study end-use applications for this collector in view of its attributes.
- o Make recommendations regarding integration of this collector into optimized systems.

INTRODUCTION

In most energy applications, solar energy does not yet have a significant cost advantage. Without substantial advantages to provide an incentive, wide spread commercialization of solar technologies will be very slow to develop. This research centers on the most expensive system component: the collector. The intent of the program is to research an approach which could reduce capital costs at the collector by half, thereby substantially improving the economics of the entire system. The issues addressed in this report include: (a). Collector Manufacturing Costs; (b). Processing Methods; (c). Material Characteristics; and, (d). Collector Performance.

Earlier research efforts by this organization have led to a solid understanding of polymeric, flat-plate collectors. Extensive materials research has resulted in development of long-lived stablized polymers.

Other designs and relevant literature have been studied in detail to judge alternative glazed collector approaches. Numerous novel design concepts have been developed, evaluated and compared to existing collectors. Computer programs have been written to predict collector performance and to test the effect of various configuration changes. Vast amounts of materials data have been compiled.

General methods have been developed to calculate materials and manufacturing costs of a collector. Thermal testing in sunlight, and in FAFCO's own solar simulator, has been used to verify computed performance. Accelerated testing used included EMMAQUA, steam, ultraviolet (UV), chemical testing and thermal aging.

During that research, one conclusion became abundantly clear: conventional flat-plate collectors have much room for improvement. By studying product literature, purchasing and dismantling commercial collectors, and by building several collectors in-house, many specific problems became apparent. To list a few:

- Complexity

  Typical commercial collectors each consisted of 50 to 70 individual parts to be assembled, with nine or more basic materials used. As a result, assembly labor was high and the potential for labor-reducing mass production techniques was limited.

- Weight

  Conventional collectors had a dry weight of 15 to 30 kilograms per square meter. This weight was necessary for structural considerations; the glazing and absorber plate extended over wide unsupported spans. High weight meant high cost of materials, as well as handling and structural support problems. Module size was limited by handling weight constraints.

- Energy Content

  Conventional collectors were assembled entirely from preprocessed materials. Most of these materials (especially metal and glass) had a high energy content in their refinement and processing. This detracted from the net energy contribution of the solar collector system.

- Installation Problems

  Most conventional collectors had no provisions for properly manifolding individual units together to form a bank of collectors. This necessitated on-site fabrication of expensive and complex pipe manifolding systems. Since installation personnel were often poorly trained or lacked technical understanding, installation errors were common. In addition, since most collectors had a small unit size, more units were required, which further complicated installation.

- Corrosion

  Corrosion was a problem with all metal absorbers, and with aluminum absorbers in particular. The usual solution was to increase wall thickness which added to weight and expense.

- o <u>Glazing Problems</u>

  In collectors with glass covers, thermal stress and impact breakage were common problems. In all conventional collectors, wind loading on the wide span of glazing presented a potential problem.

- o <u>Plate Coating Deterioration</u>

  Absorptive coatings were inherently subject to peeling and/or deterioration with age. Selective coatings were especially subject to deterioration because of their high stall temperature and delicate nature.

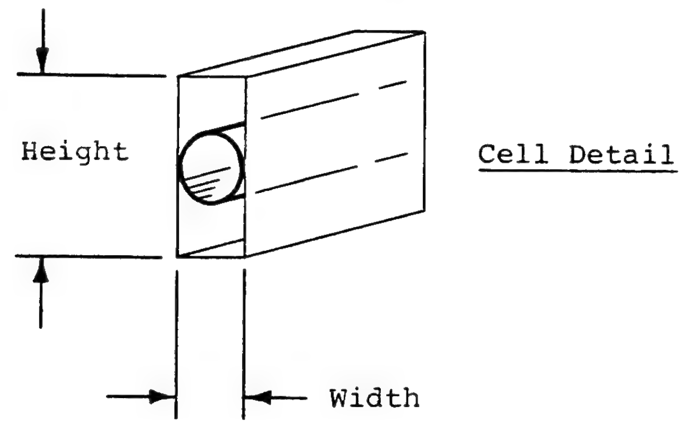
During FAFCO's past research efforts, a design approach was conceived which was thought to have potential for improving on cost, installation, durability and efficiency.

The concept called for a radical departure from conventional "box-type" flat-plate collectors. The glazing, absorber and insulation would be integrated into a single structure, thus eliminating the box frame and its functions of support and enclosure. The result would be a simple, low weight and low cost flat-plate collector that could be mass produced. Figure I is a sketched sectional view of this design.

The collector absorber body is an extruded section consisting of parallel cylindrical channels. The absorber material is selected for high temperature characteristics, absorptivity, ultraviolet stability and compatibility with collector fluids. The glazing is an extruded thin wall coaxial profile structure combined directly to the channels. This material is selected for transparency, thermal and ultraviolet stability.

Dimensions of the glazing cross-section and the ratio of height to cell width can be altered by design, and will vary the efficiency and stall temperature of the collector. The extruded sheet(referred to as a multiple coaxial composite) is a semi-rigid, single integrated structure. The extruded composite can be attached to a manifold by any of several methods. Figure I illustrates one example of how this might be accomplished. The result is a glazed, semi-insulated collector with integral

COAXIAL COLLECTOR CROSS-SECTION



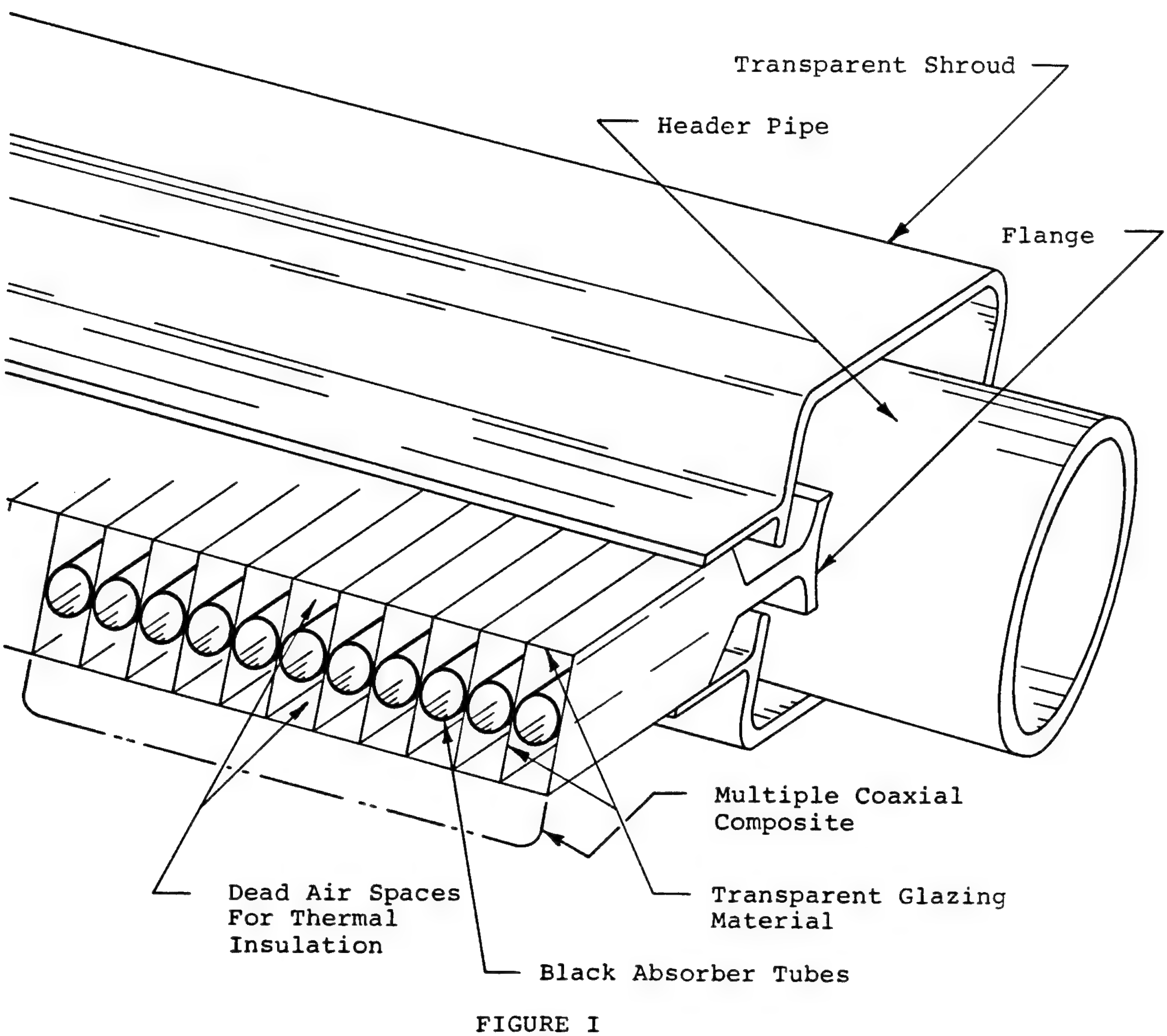


FIGURE I

manifolds. Simple additions can make the collector self-racking and fully insulated.

Several promising polymers are available, at moderate prices, for use in development of a higher performance collector. Comparison with conventional collectors reveals dramatic potential cost reductions with the coaxial concept.

The remarkably high calculated efficiency of this configuration has been confirmed experimentally by stall temperature tests of small fabricated models. The improved efficiency is caused by high transmission of the glazing and by the internal rib structure. A plastic glazing with high light transmission (similar to the best glass) is possible by making the plastic extremely thin. A thin glazing is possible because of the excellent support provided by the internal ribs. The ribs do conduct some heat away from the black waterways, however, this effect is far more than offset by reductions in other heat losses.

The ribs do provide a "honeycomb" effect by reducing convection of the trapped air. The ribs effectively interpose a surface "black" to infrared radiation. Since the ribs are at a temperature greater than the outer glazing surface, and because the ribs represent the majority of the field of view for the absorber surface, radiant heat loss is substantially reduced.

The configuration is symmetrical, and can be utilized on both sides as the glazing degrades. In this way the potential life expectancy is doubled.

The coaxial concept is a direct conversion process from inexpensive raw materials to finished solar collectors. It is a logical extension of existing and proven technology. The potential of such a process is enormous, and the uncertainties substantial. By researching the areas of uncertainty with respect to the problem areas of material properties, processing methods, collector manufacturing costs, installation costs and long-term performance, the objective is to discover a process and materials that can be proven practical and attractive for production of solar collectors.

PROGRAM

This project analyzes the coaxial design concept and establishes a definition of the operating environment of the materials. In view of this environmental definition, this study also conducts a search for suitable materials. Candidate materials then undergo a thorough evaluation by accelerated and non-accelerated environmental exposure testing.

Simultaneously, preliminary processing tests are performed, which lead to the eventual extrusion of the candidate polymers. This is done in an attempt to produce a coaxial one-celled composite unit, which is the first step in the extrusion of a multiple coaxial composite collector (as shown in Figure I).

I. Methods and Procedures

A. Environmental Definition

The environmental definition describes the internal and external operating conditions of the collector. It is the primary consideration in the development of design, and the seeking of materials to be used. In order to ascertain these operating conditions, certain basic assumptions are required. These assumptions include the following

Basic Assumptions

1. Configuration

   The configuration is defined by Figure I.

   Dimensions can be varied to meet design requirements.

2. Aperture

   The aperture is the opening or projected area of a solar collector through which the unconcentrated solar energy is admitted to the absorber for utilization.

   For purposes of this study, the net aperture areas are 1.219 x 3.048 meters, 3.176 square meters, or 1.219 x 2.438 meters, 2.972 square meters.

3. Pressure

   Pressure of the collector is determined as a measure

of normal operating conditions.

The collector fluid system should be a vented atmospheric drain-down system. For a closed system, there should be adequate expansion tank volume and pressure/temperature relief, with fluids that will not freeze under defined operating conditions.

Given the configuration size and internal pressure for the absorber, hoop stress can be calculated and used for materials evaluation purposes.

The normal operating pressure of the collector must not exceed 0.207 MN/m^2 (30 psi), at normal operating temperature.

4. Flow Characteristics

These characteristics ensure optimum flow distribution, through a collector array, by developing a desired curve that relates flow rate to pressure drop.

The design range must be from 3.785 liters per minute to 18.93 liters per minute.

Head loss versus flow rate for the proposed collector is shown in Figure II. This assures good flow distribution between collectors arranged in large parallel banks.

5. Thermal Performance

The minimally acceptable, assumed collector performance curve is represented in Figure III.

The collector must conform to the no-flow, 30 day degradation test, as established by the California Energy Resources Conservation and Development Commission (CERCDC)(1).

6. Chemical Resistance

The collector must be compatible with common collector fluids, such as chlorinated pool water, ethylene glycol, water containing copper-ions, etc. This assumption must be made because these represent the interactions that occur during normal operation.

7. Thermal Shock

The collector must meet the water spray requirements of the CERCDC (1).

PROPOSED COLLECTOR
FLOW CHARACTERISTICS

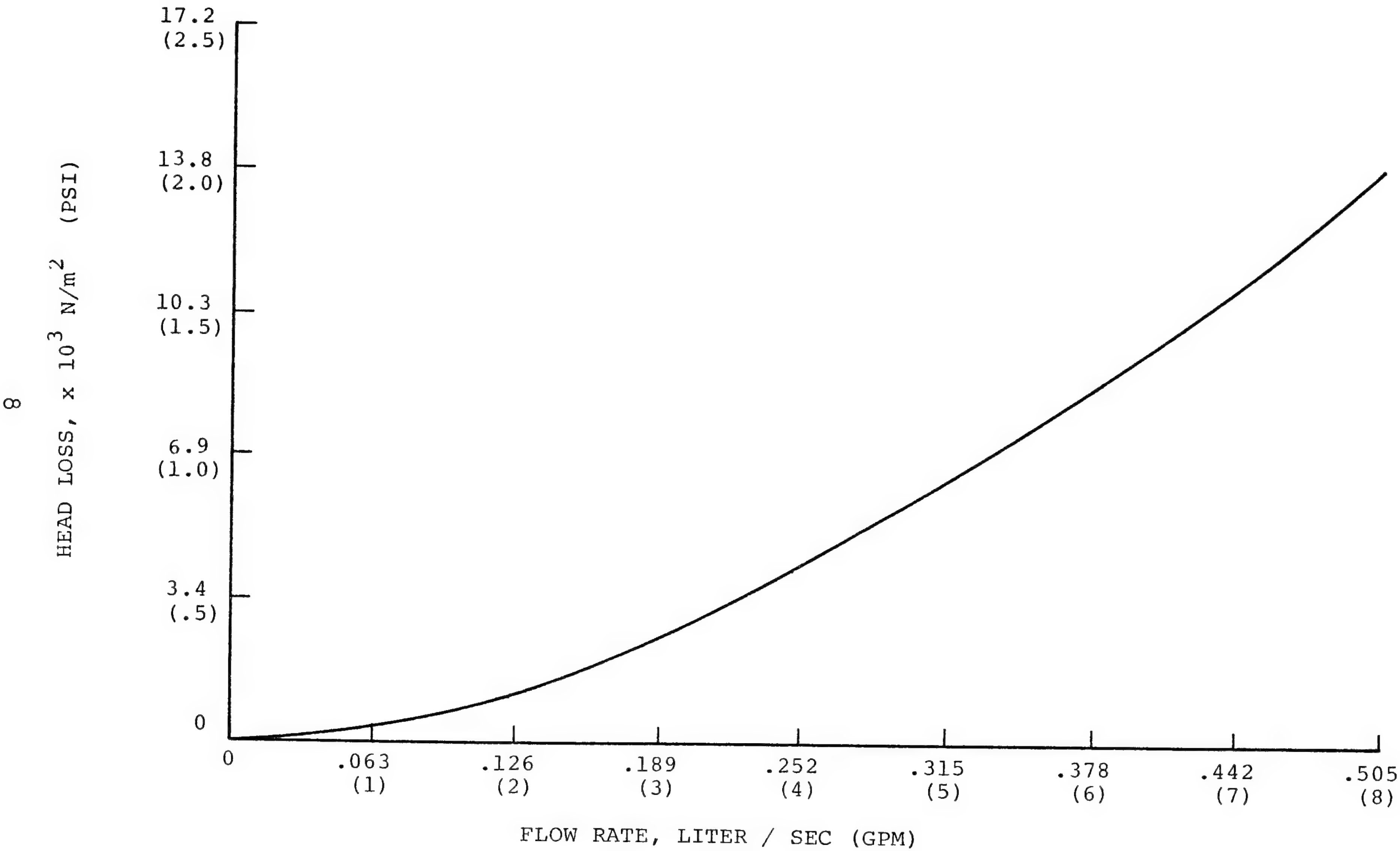


FIGURE II

PROPOSED COLLECTOR
THERMAL PERFORMANCE CURVE

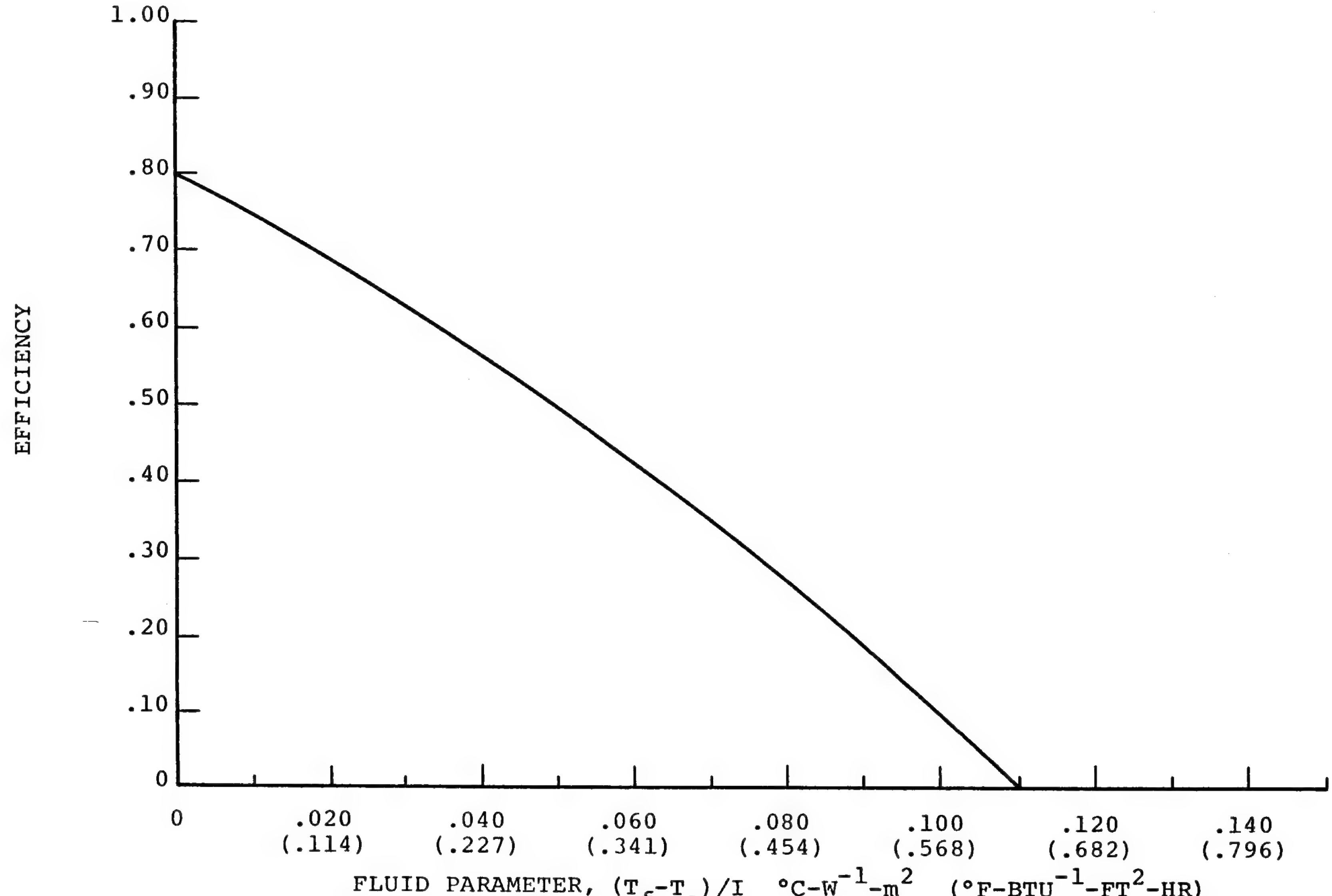


FIGURE III

The collector must meet the cold fill requirements of this same commission (1).

8. Impact Resistance

The initial impact resistance of the materials must be greater than 500 J/m.

9. Freeze Protection

The collector should be drained prior to freezing, or should make use of an approved anti-freeze solution as the collector fluid.

10. Water Diffusion and Condensation

During normal operating conditions, thermal performance must not be impaired by condensation on the internal glazing surfaces.

11. Life Expectancy

The service life expectancy must be a minimum of 15 years. The collector must be warranted to applicable CERCDC regulations.

Evaluation and Testing Parameters

1. Computer Simulation

A computer model is developed to determine the effects of collector design parameters and ambient conditions on collector behavior.

The computer program is developed after the collector mathematical model is formulated. The equations comprising the model are derived from common heat transfer expressions for the proposed configuration. The computer solution of these equations is expressed as a Hottel-Whillier-Bliss plot of the collector (efficiency vs. fluid parameter). Solutions are obtained for various parameters of design.

An outdoor stagnation test is run on a fabricated collector model. Stagnation intercept values are then calculated. The results are compared to a computer model for the same configuration.

The fabricated model is constructed by placing L-shaped sections of polycarbonate on the polyolefin

absorber, as shown in the stagnation sample drawing (Figure IV) and the photograph on the next two pages.

The individual glazing units are welded together with a platen weld; the rib/glazing structure essentially rests in the interstices between the absorber tubes. Three type T thermal couples are inserted inside the absorber tubes in order to determine the stagnation temperatures. Temperature measurements are obtained utilizing a Fluke, model 2176A, digital thermometer.

Wind velocity is determined using a Prosser, model AVM 501TC, hot wire anemometer air velocity meter.

Various backing surfaces are investigated. A plywood surface is used in order to simulate a roof mount. Standard fiberglass corrugation is tried, as well as air and urethane, to permit comparisons of various types of mounting methods and mounting materials.

The verified computer model can be used to determine maximum stagnation temperature of the glazing and absorber materials for various design parameters, such as height of glazing, various values of wind velocity and back insulation.

2. Material Stress

(a). Hoop Stress

From the internal pressure and absorber configuration required, the hoop stress can be calculated.

The information obtained determines equivalent tensile stress occurring in the absorber material. Similar values are used during steam testing of the absorber materials.

(b). Thermal Stress

Since it is not possible to manufacture an entire collector to be subjected to the thermal shock test requirements, thermal stress calculations are performed simulating the assumed worst case shock condition, on a single cell basis. The results of

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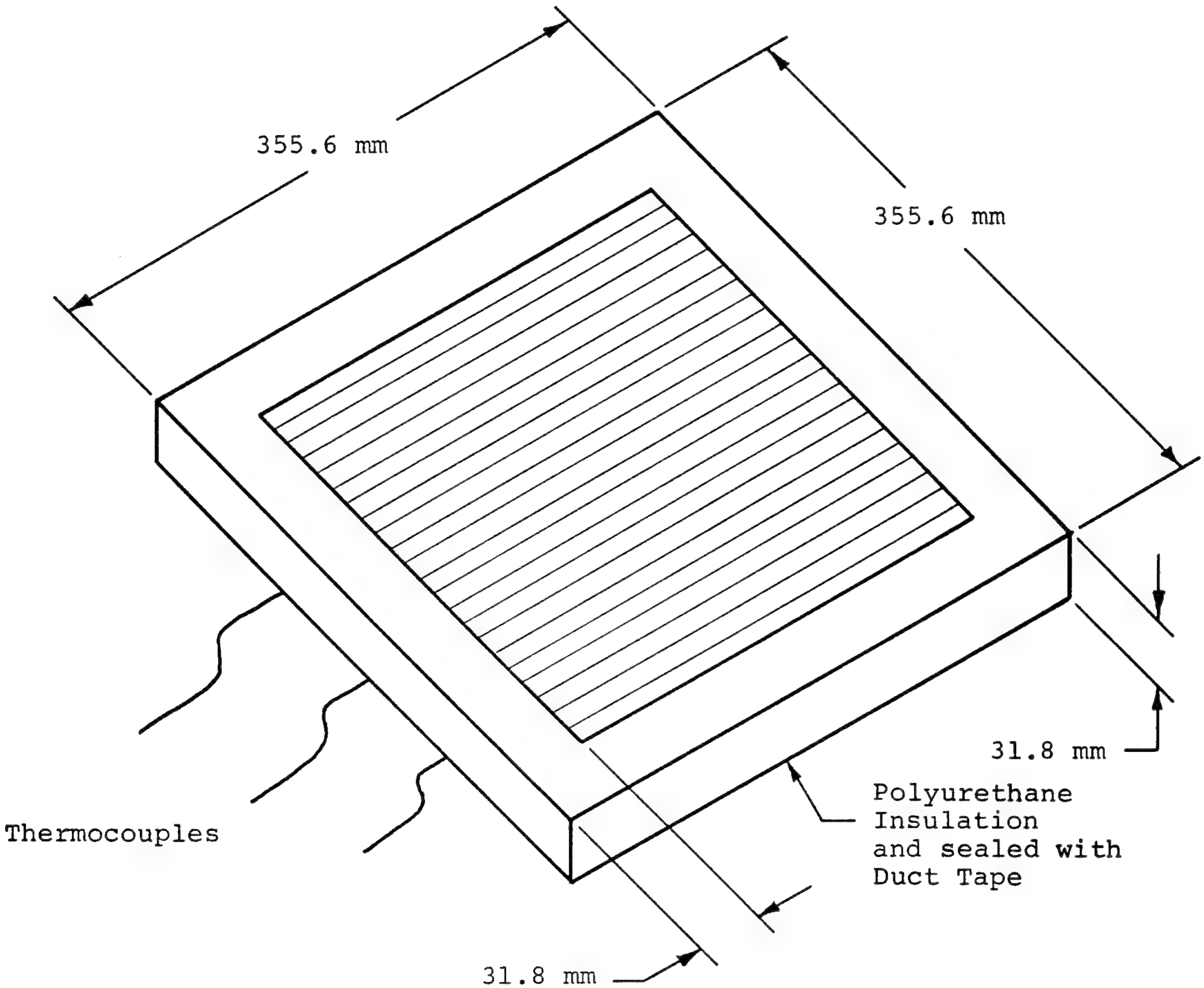


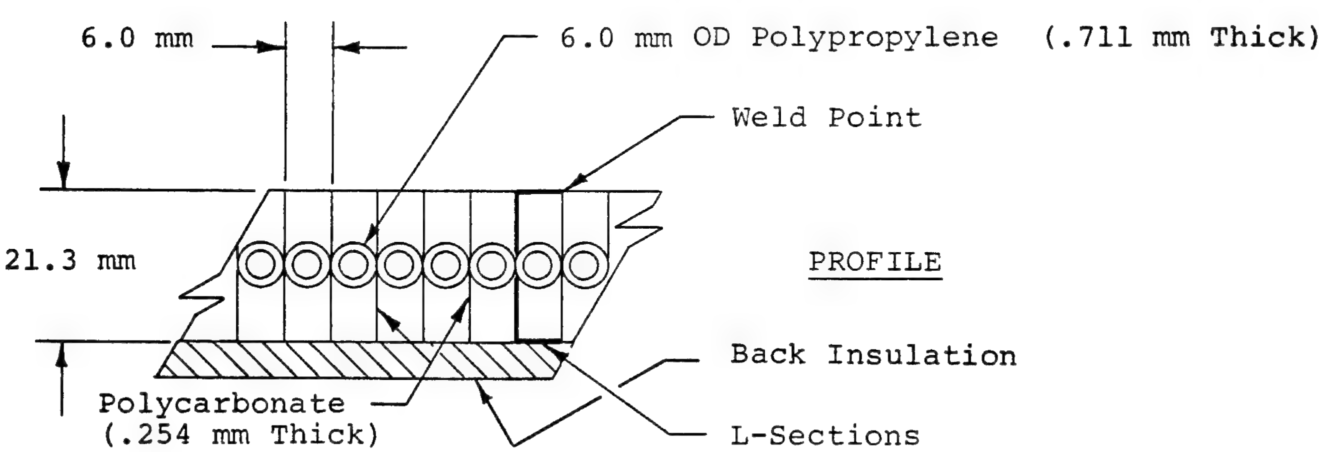
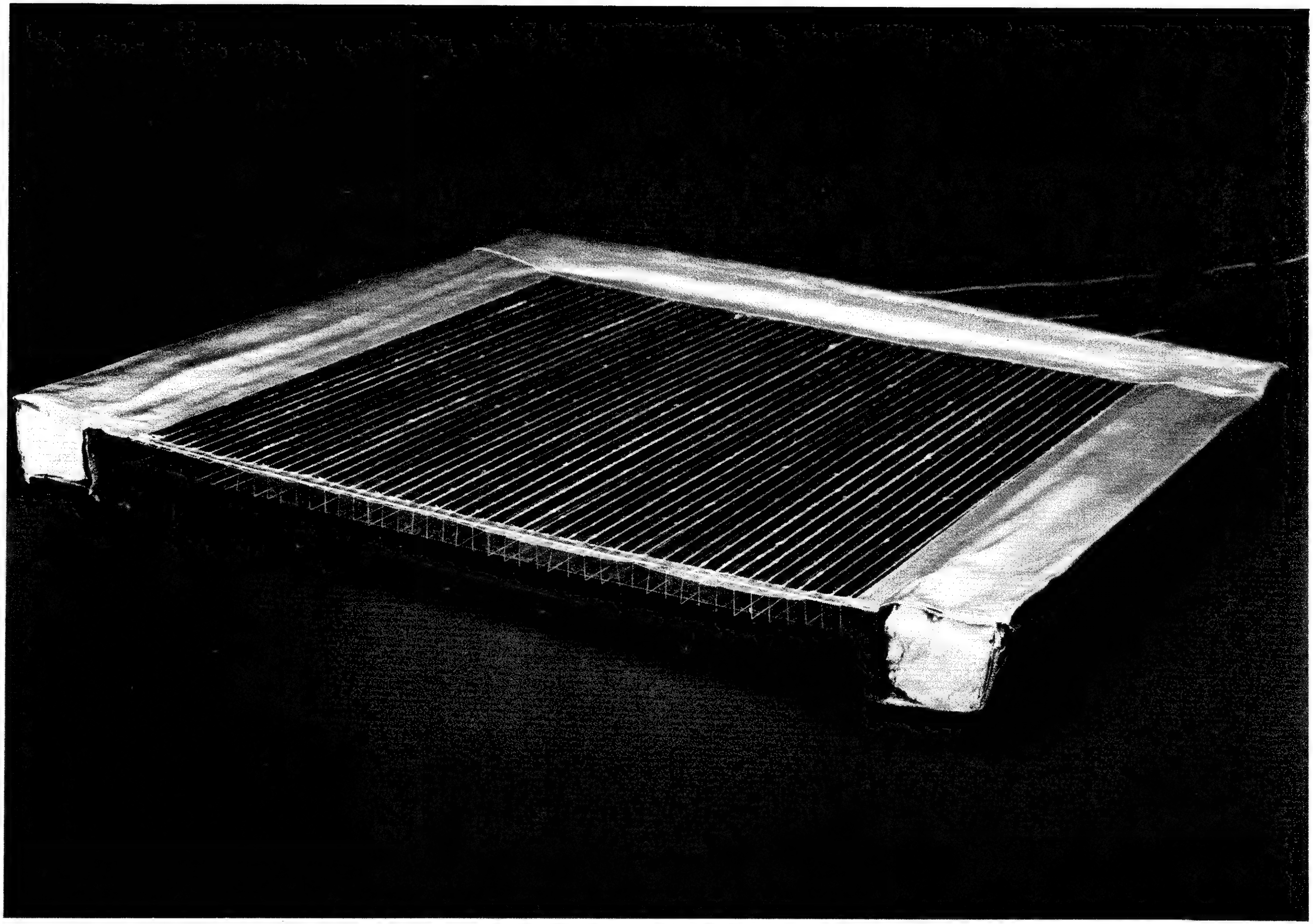


FIGURE IV



STAGNATION SAMPLE

these calculations provide the shear strength required between the absorber tube and glazing material.

From the miscibility and weldability tests, the tensile strength of this bond is measured and compared with the above value.

3. Water Diffusion and Condensation

Calculations are performed to investigate the effects of water vapor transmission through the absorber material. The results of these calculations indicate the air flow rate,in the space between glazing and absorber, which is necessary to remove water vapor.

B. Materials Search

By utilization of a preliminary screening, a search is conducted to find materials suitable for use as an absorber and as a glazing. In addition, recommendations on additives and supplemental coatings are sought from manufacturers.

The first step in these investigations is to determine the properties the materials must possess. And then, by providing a table of material properties, profiles of each candidate material are examined, and a comparative analysis performed. In this manner the leading candidate materials are established.

Thermoplastic materials, from which the absorber will be extruded for the proposed coaxial extrusion, must be:

- o Compatible with the glazing material during a co-extrusion or bonding process;
- o Capable of being compounded with carbon black;
- o Resistant to ultraviolet degradation;
- o Hydrolytically stable at elevated temperatures, under stressed conditions, to various collector fluids (including ethylene glycol, chlorine and water containing copper-ions).

Thermoplastic materials, from which the glazing will be extruded, must meet the following requirements:

- o Light transmissivity greater than 90%;
- o Transmissivity must not drop more than 10% during

life expectancy of collector;

o High resistance to ultraviolet degradation;

o High resistance to moisture and normal weathering.

C. Materials Evaluation

In this section the materials selected from the preliminary screening are subjected to a number of tests, as follows:

1. Test Methods

(a). Tensile and Elongation

Tensile strength is the maximum stress a material is capable of sustaining. It is calculated from the maximum load during a tension test carried to yield or rupture and the original cross-sectional area. (2)

Elongation is the increase in gage length of a tension specimen, expressed as a percentage of the original gage length. (2)

Tensile strength at break and yield strength is calculated in accordance with ASTM D638. (3)

This study uses the ASTM D1708-66, Tensile Properties of Plastics by Use of Microtensile Specimens (3), for tensile testing of the various candidate materials. It utilizes a universal tensile tester and microtensile specimen, with a cross-head separation speed preset at 5.08 cm per minute. This test is a method for determining the comparative tensile strength and elongation properties of plastics, before and after accelerated environmental exposure.

(b). Transmissivity

Transmittance is the ratio of the radiant flux transmitted by a specimen to the radiant flux incident on the specimen.

For this study a modification of ASTM D1746-70, Transparency of Plastic Sheeting, is used to measure transmissivity. (3)

A Leitz photometer is modified by:

o Utilizing a circular aperture of 0.32cm diameter; and,

o Modifying photocell size and placement to accept direct and diffuse radiation, up to an angle of 25^{o}, with respect to normal.

The light source is incandescent, as specified in ASTM standards.

Glazing materials, with and without coatings, are evaluated before and after accelerated exposure. In addition, UV-resistant coatings are examined with a Beckman spectrophotometer prior to exposure, in order to measure the UV screening effect of such coatings.

2. Environmental Exposure

These tests include both commonly used and specially designed methods that are tailored to actual operating conditions of the proposed collector.

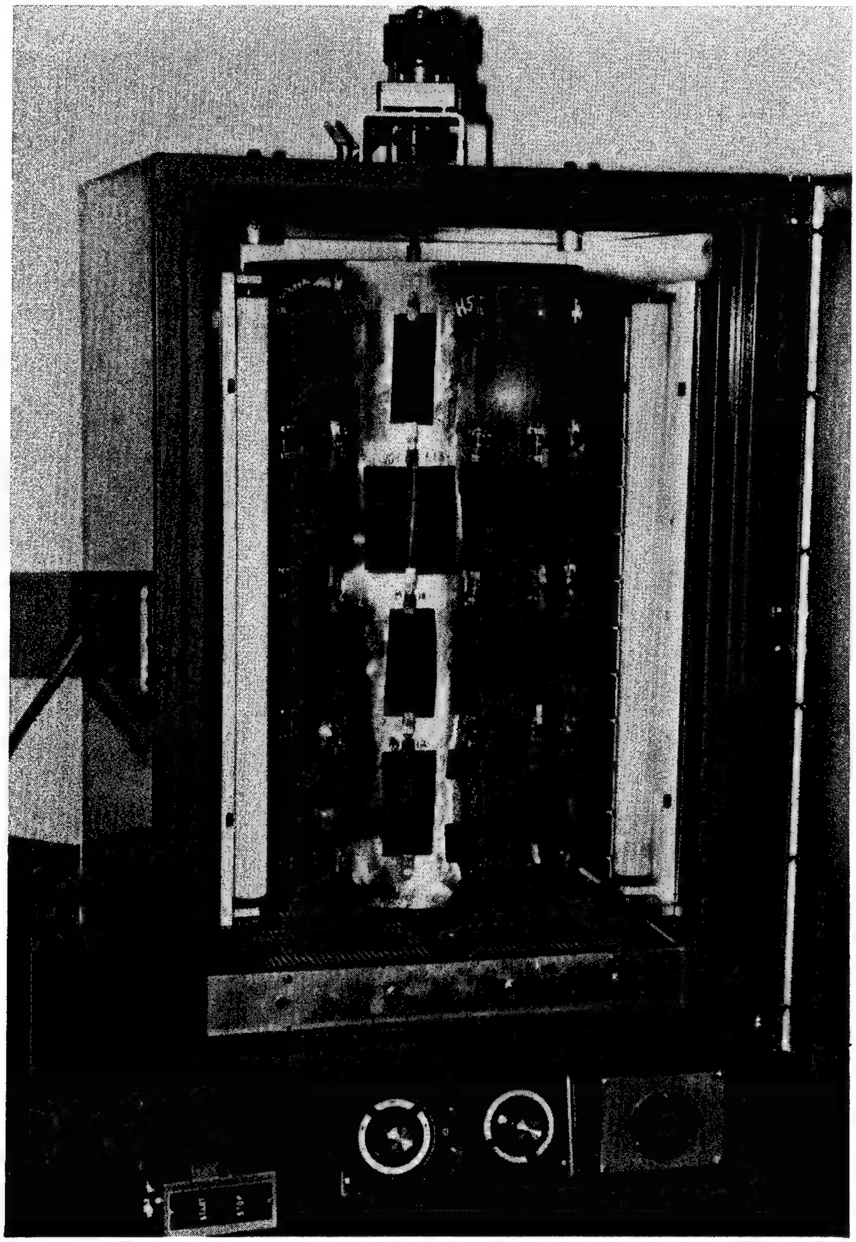
(a). Accelerated

Before and after each accelerated exposure, tensile strength and elongation are measured. For each measurement three microtensile samples are prepared, tensile tested and the values averaged.

I. Thermal Oxidation

Polymers, like other organic materials, are susceptible to attack by oxygen. Elevation of temperature in an oxygen environment accelerates this oxidation process. Oxidation reactions of the polymer leads to cross-linking and chain scission (the breaking of the long chains, forming carbonyl groups).

To simulate collector stagnation conditions, candidate materials are exposed to $120^{o}C$, $150^{o}C$ and $200^{o}C$ air circulating ovens.(A photograph of this oven is on the next page.)



THERMAL AGING OVEN

Before and after the prescribed periods of time, transmissivity and tensile properties are measured. Transmissivity measurements are made on the glazing materials. Tensile properties are measured on the glazing and absorber materails.

II. Steam Aging

The absorber material samples are exposed to various saturated steam conditions in order to determine the hydrolytic stability of the materials at operating, and stagnating, conditions.

These absorber samples are exposed to saturated steam at 100°C and 120°C. Thickness of the sample is chosen to reflect the proposed absorber wall thickness. These samples are subjected to 0.0 MN/m^2, .69 MN/m^2 and 1.38 MN/m^2 tensile stress, during the test period. These tensile stress levels are equivalent to the hoop stress produced from internal fluid pressure in the absorber channel.

The test device is shown in Figure V.

III. EMMAQUA (Equatorial Mount with Mirrors for Acceleration) Testing

EMMAQUA tests, performed by Desert Sunshine Exposure Testing (DSET) in Arizona, use a device consisting of an equatorial mount with ten flat mirrors that "track" the sun. The apparatus is positioned in such a way that the incident angle of the sun's rays is approximately 90 degrees throughout the day. Each mirror reflects between 70 and 80 percent of the solar radiation the sample would have absorbed, in the same interval, using only an equatorial mount.

Forced air, directed onto and under the test samples to prevent overheating, maintains sample temperature in approximately the same range as develops with a fixed mount at 45°S.

STEAM AGING TEST APPARATUS

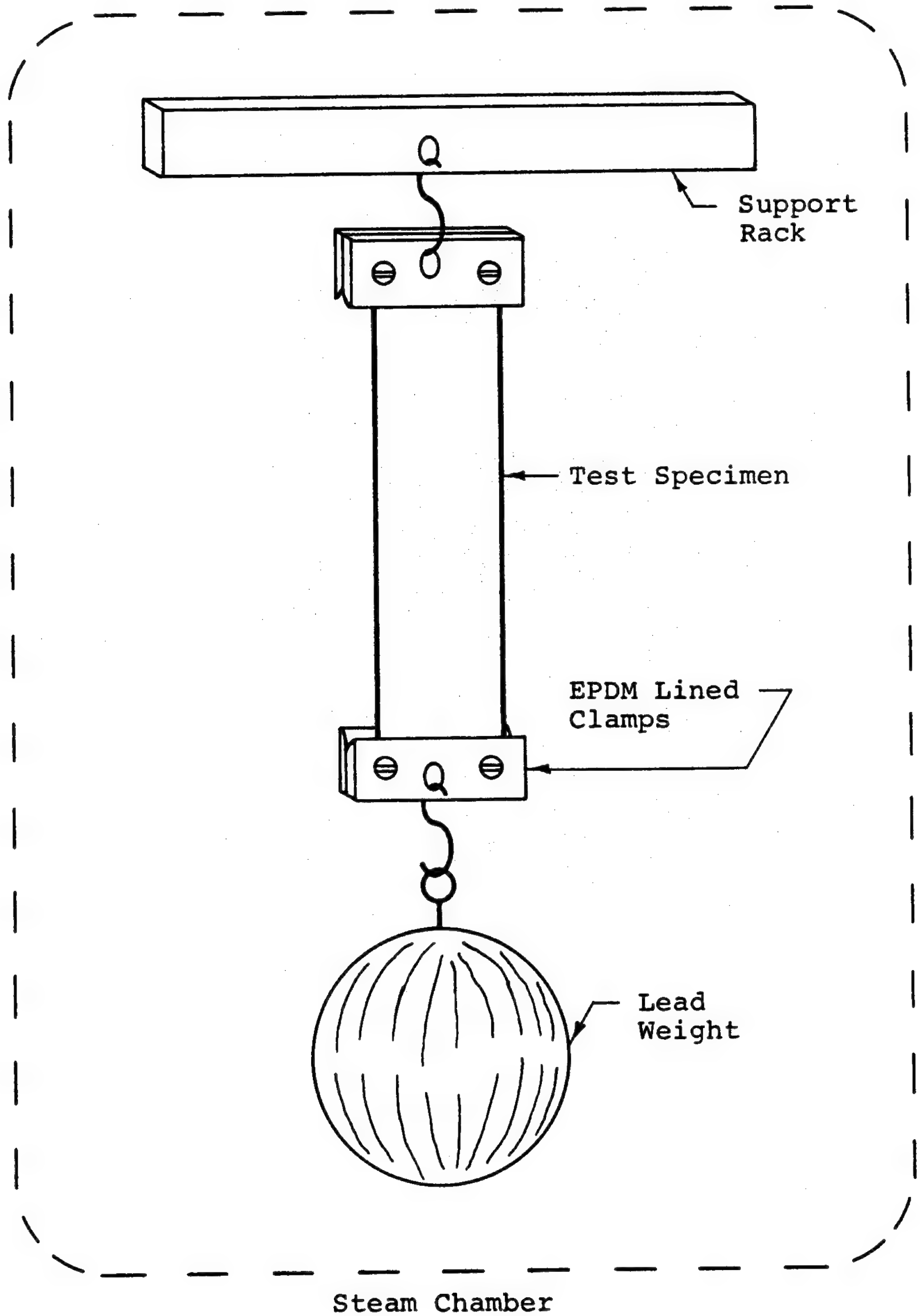


FIGURE V

Samples are sprayed with triple-distilled water for 8 minutes out of each hour of exposure.

Material samples are in sheets 2.54 cm wide by 12.7 cm long. Absorber materials are 0.508 mm thick, and glazing materials are 0.127 mm to 0.254 mm thick. (Refer to Exhibit B in the Appendix for specific thicknesses of glazing materials for each test.)

In order to investigate the absorber material's effectiveness in UV blocking, a stainless steel fixture is designed. This stainless steel fixture holds layers of glazing and absorber material. These layers simulate the effect to which the absorber will be exposed in the proposed configuration.

IV. Ultraviolet Testing

Although the weathering of plastics is dependent upon many environmental factors, it is generally accepted that a relatively narrow band of the electromagnetic spectrum of sunlight is responsible for the primary photo-chemical processes in the oxidative degradation of polymers.

For this study, the fluorescent black-white light unit is chosen for the UV exposure. The sources of the radiation are a 40 Watt, Sylvania F-40 BLB lamp and General Electric 40 Watt FS-40 white lamp.

The radiation of the tester approximates solar radiation. One hundred hours of exposure in the tester is equivalent to one month of outdoor exposure in the New Jersey area.

EMMAQUA testing is also used for investigating sample degradation. However, the UV tester is useful for preliminary evaluation.

V. Chemical Testing

Commonly used collector operating fluids frequently degrade plastics. Typical components are chlorine and organometallic solutions which are often used as algaecides. The chlorine can be a strong oxidant, while copper acts as a catalyst in the depolymerization of the polymer. In addition, ethylene glycols, which are used as anti-freeze agents, can degrade the material by functioning as a plasticizing and hydrolyzing agent.

At an elevated temperature of 75°C, the absorber materials are exposed to the above chemical solutions in these concentrations: 100% ethylene glycol, 25 ppm copper solution and 50 ppm chlorine solution. These concentrations are higher than normally encountered, which produces the accelerated effect.

(b). Non-Accelerated

I. UV Screening of Coatings

Glazing surface coatings are required to shield the glazing and absorber from the potential degradation by the UV portion of the solar spectrum.

A Beckman model spectrophotometer and a review of the available literature are used for determining the UV screening effect of the various coatings.

Samples, with and without coatings, are obtained in 0.254 mm thicknesses. They are then subjected to wavelengths of 200 to 700 nm, utilizing a 100 nm/minute drive and 5.08 cm/minute chart speed, normal slit program.

II. Thermal Shock Resistance of Coatings

The glazing coatings must not peel, crack or deteriorate through repeated thermal cycling.

Thermal cycling is performed by subjecting coated samples of polycarbonate (0.508 mm) to thermal shock tests, between 120^{o}C heat and 0^{o}C water.

D. Preliminary Processing Tests

Preliminary tests provide information regarding what might be expected from the candidate materials during processing. Since the materials are amorphous (as contrasted to the crystalline structure currently in use by FAFCO), a complete literature search, in conjunction with the manufacturers' recommendations, is required to understand the problems that may be encountered. These preliminary processing tests enable modifications to be made in order to perform the processing experiments for coaxial extrusion.

The following list consists of the preliminary processing tests utilized for this study.

1. Moisture Absorption

Since the candidate materials may be hygroscopic, before processing they require drying at elevated temperatures in a dehumidifying oven. Excessive moisture levels cause extruded profile to exhibit severe bubbling, unsatisfactory appearance and degraded strength.

Moisture absorption rate is of major importance because after-forming operations must occur before unacceptable moisture levels occur. Manufacturers do provide moisture absorption rates. However, such published data is not useful for the specific process used in this study. A graph is required showing moisture absorption at normal production conditions. This graph must be defined in minutes, not hours (as is the case with the manufacturers' curves). Therefore, a method to accomplish this, established by Imperial Chemical Industries(I.C.I.), is modified and implemented as follows:

Samples are completely dried, as recommended by the manufacturer. Each sample is then exposed to 20°C air, at 85% relative humidity, in 15 minute intervals. After exposure, each sample is heated rapidly to 200°C and examined for severity of bubbling. Maximum relative moisture content and a minimum melt processing time is then established for the candidate materials.

2. Melt Behavior

A considerable body of knowledge already has been accumulated regarding the melt behavior of polyolefin materials. An intensive investigation of published information is conducted to determine the melt behavior of the candidate materials. The candidate materials necessitate changes in FAFCO extrusion equipment to accommodate their different processing characteristics.

3. Weldability

Since the collector configuration requires bonding between dissimilar materials, a degree of compatability is required. The interface must be able to withstand the stresses to which it will be exposed.

Samples are bonded by melting surfaces, and joining via the application of pressure.

A hot air welding gun, hot platen and an infrared heating source are used to melt the material surfaces.

Samples are tested for tensile strength of the bond.

4. Miscibility

The blending properties of the candidate glazing and absorber materials must be investigated, because mixing occurs during flange formation and co-extrusion.

<u>Melt Blending</u>

Melt blending is performed in an aluminum mold having a chamber 25.4 mm in depth and 12.7 mm in diameter. The mold is very slowly elevated to an optimum melt temperature, and held at that temperature for 20 minutes. A cover on the chamber distributes the heat evenly. A

second material is then slowly lowered into the melt. The sample is allowed to cool and cut in half longitudinally to investigate the boundary conditions, and to measure the tensile strength.

Flange Formation

Formation of a flange is one method of connecting the absorber body to the header pipe. Normally, the absorber is forced into a hot die which is then cooled. For the coaxial configuration it is necessary to trim the glazing from the absorber by 76 to 102 mm to prepare for flange forming. (It should be noted that glazing material remains between the absorber channels.)

To investigate the forming of a flange from absorber material (with glazing material between channels), a round coaxial tube composite of absorber and glazing material is fabricated. This is slowly fed into a flange former at an elevated temperature, as shown in Figure VI.

The flange former is cooled internally with water. The resulting sample is removed and evaluated for shrinkage, bubbling and blending.

E. Processing Experiments

The process experiments lead to the one cell, coaxial extrusion of the assumed configuration.

These experiments consist of (1). a preliminary extrusion, which is the extrusion of round tubing utilizing the glazing and absorber materials; (2). a single (non-coaxial) extrusion, which is the extrusion of the glazing material in the rectangular configuration (as shown in Figure VII), and the extrusion of the absorber material (as shown in Figure VIII); and, (3). a coaxial extrusion, which is the extrusion of the absorber and glazing materials as shown in Figure IX.

Modifications to existing FAFCO extrusion equipment are required in order to accomplish the preliminary extrusion.

EXPERIMENTAL FLANGE FORMER

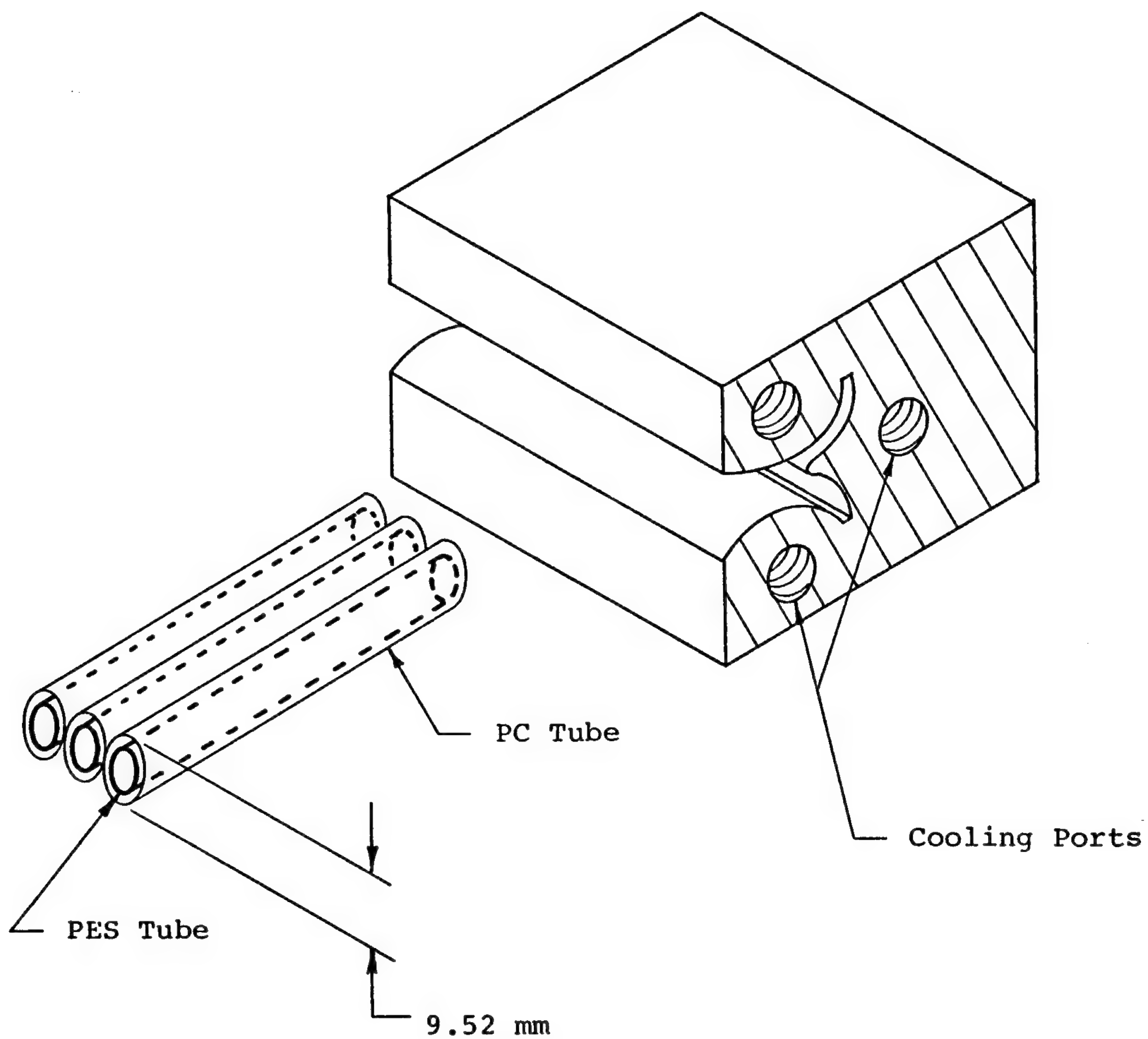
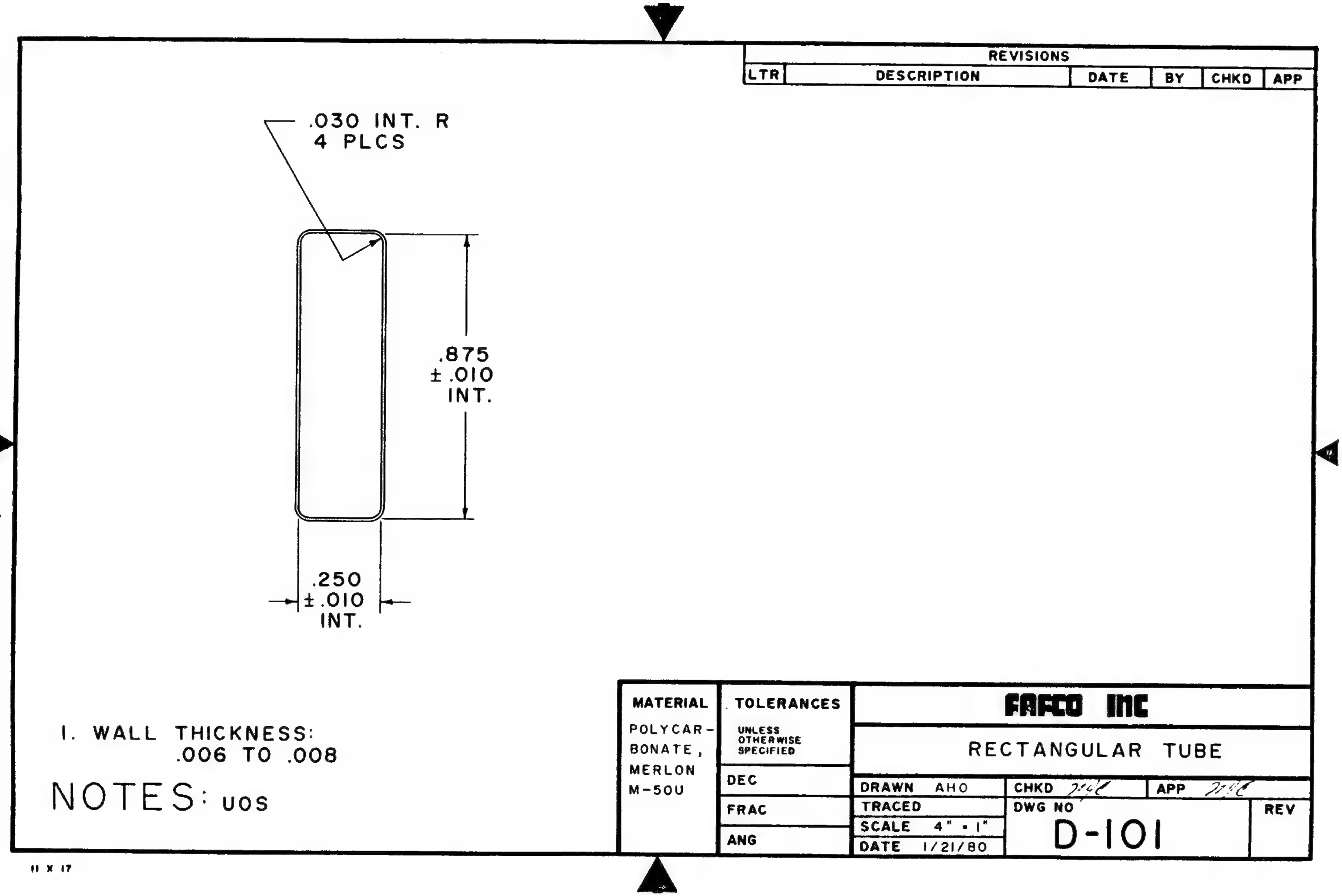


FIGURE VI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CHKD
APP
DWG NO
D-101
REV
11 X 17

FIGURE VII

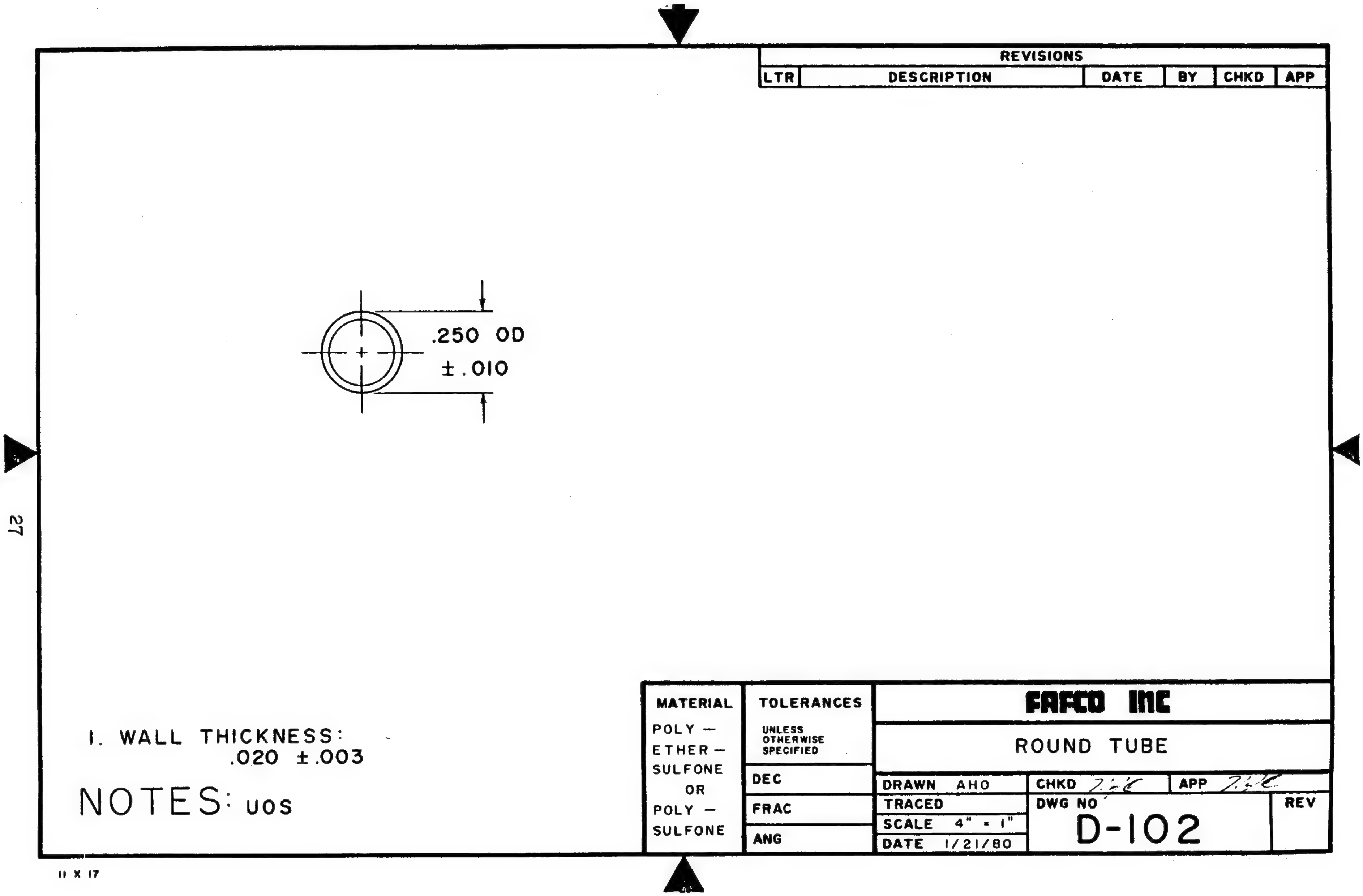

REVISIONS
LTR
DESCRIPTION
DATE
BY
CHKD
APP
.250 OD
±.010
1. WALL THICKNESS:
.020 ±.003
NOTES: UOS
MATERIAL
POLY — ETHER — SULFONE OR POLY — SULFONE
TOLERANCES
UNLESS OTHERWISE SPECIFIED
DEC
FRAC
ANG
FAFCO INC
ROUND TUBE
DRAWN AHO
TRACED
SCALE 4" = 1"
DATE 1/21/80
CHKD
APP
DWG NO
D-102
REV
11 X 17

FIGURE VIII

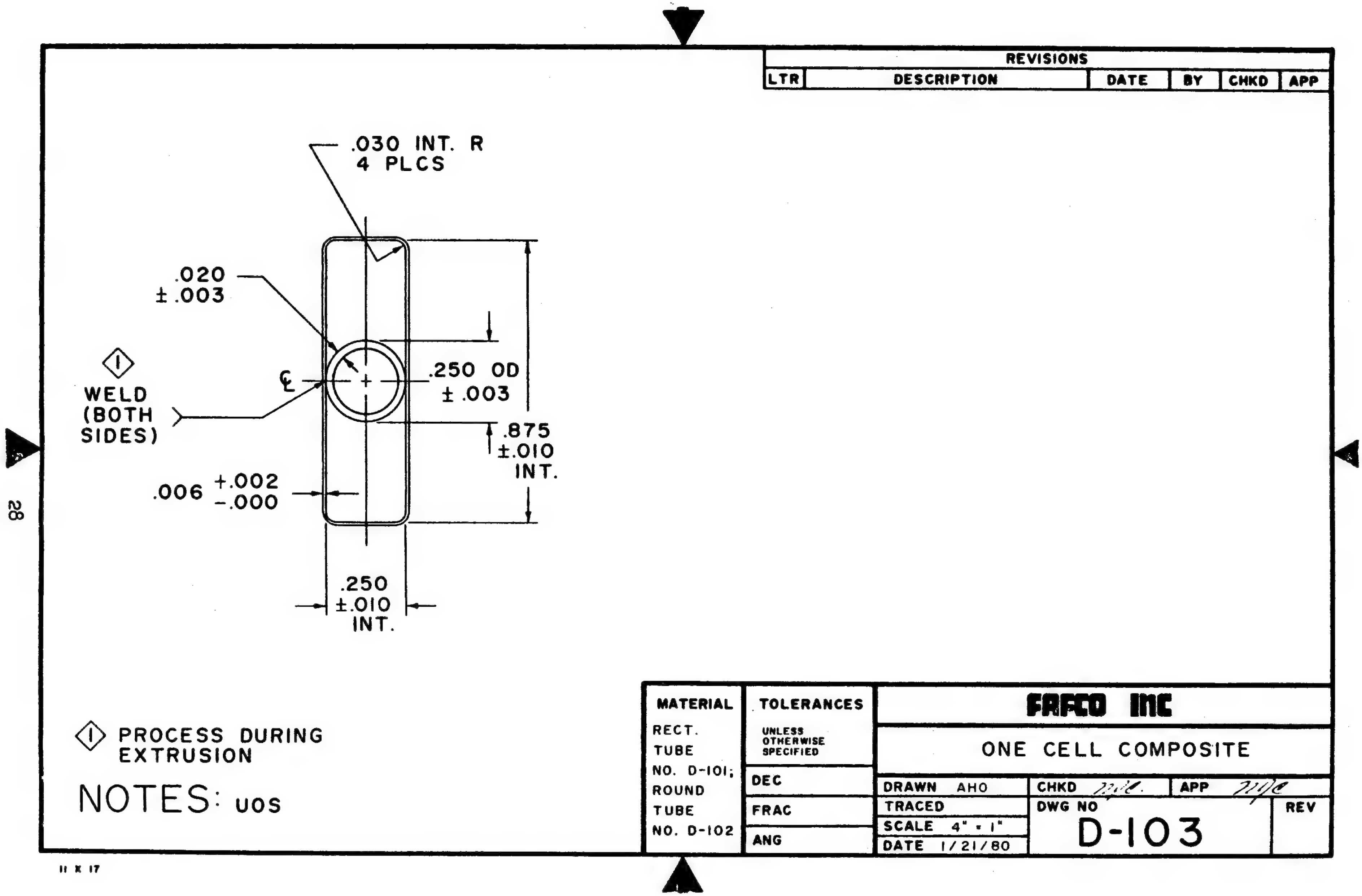

REVISIONS
LTR
DESCRIPTION
DATE
BY
CHKD
APP
.030 INT. R
4 PLCS
.020
±.003
1
WELD
(BOTH
SIDES)
℄
.250 OD
±.003
.875
±.010
INT.
.006 +.002 -.000
.250
±.010
INT.
1
PROCESS DURING
EXTRUSION
NOTES: UOS
MATERIAL
RECT.
TUBE
NO. D-101;
ROUND
TUBE
NO. D-102
TOLERANCES
UNLESS
OTHERWISE
SPECIFIED
DEC
FRAC
ANG
FAFCO INC
ONE CELL COMPOSITE
DRAWN AHO
TRACED
SCALE 4" = 1"
DATE 1/21/80
CHKD
APP
DWG NO
D-103
REV
11 X 17

FIGURE IX

In addition, development of dies and forming equipment is required to accomplish the single and coaxial extrusions.

II. Results

A. Environmental Definition

Evaluation and Testing Parameters

1. Computer Simulation

Key results and required assumptions for ten different design and ambient conditions are summarized in Table 1. Additional specific environmental assumptions are indicated in Exhibit A in the Appendix.

Cases 1 through 3 are chosen to illustrate the effect of over-all collector height (top cover to bottom cover), keeping all other parameters constant. Cases 4 and 5 illustrate the effects of using two different thicknesses of polyurethane foam on the back. Cases 6 and 10 approximate the conditions and dimensions corresponding to those used in an experimental stagnation sample test. Cases 7 and 8 illustrate the effect of ambient wind speed. Case 9 illustrates the effect of a copper absorber plate on thermal performance.

The computer case number 6 is used to determine the maximum use temperature for glazing and absorber materials, since this case most closely reflects the severest operating conditions and optimum collector configuration.

The absorber continuous temperature is determined from the T_{absl} column (Exhibit A in the Appendix) and is 155°C.

The temperature of the glazing material varies from 100°C at the surface, to 155°C at the absorber, as shown in the T_{ci} column of Exhibit A in the Appendix. Due to the temperature gradient in the glazing material a representative continuous use temperature of 120°C. is chosen.

Stagnation temperatures are measured during the

TABLE I

COAXIAL COLLECTOR COMPUTER MODEL
PERFORMANCE COMPARISON FOR TEN CASES

I=910 W/m, except as noted

	CONDITIONS					X intercept			CHARACTERISTICS @ X=.045								
CASE	HEIGHT mm	BACK mm MAT	Vwind m/s	Tamb DegC	Yint	SI UNITS	ENGL UNITS	Eff	Qfront W/m2	Qribf W/m2	Qback W/m2	Qribb W/m2	Grf	Nuf	Grb	Nub	
(1)	19.1	.203 PC	0.0	21.1	.852	.0842	.478	.437	-321	-33	-191	-36	384	1.0	455	1.0	
(2)	22.2	.203 PC	0.0	21.1	.852	.0883	.502	.463	-310	-29	-179	-31	811	1.0	961	1.0	
(3)	25.4	.203 PC	0.0	21.1	.851	.0920	.523	.480	-303	-25	-170	-27	1462	1.1	1764	1.0	
(4)	19.1	12.7 PU	0.0	21.1	.856	.1275	.724	.598	-321	-33	-45	-1	384	1.0	111	1.0	
(5)	19.1	25.4 PU	0.0	21.1	.857	.1350	.767	.619	-321	-33	-26	-0	384	1.0	62	1.0	
(6)	22.2	25.4 PU	0.2	37.5	.849	.1262	.717	.594	-334	-21	-36	-1	748	1.0	144	1.0	(a)
(7)	19.1	.203 PC	2.2	21.1	.832	.0650	.369	.277	-405	-50	-253	-49	615	1.0	646	1.0	
(8)	19.1	.203 PC	4.5	21.1	.822	.0586	.333	.199	-446	-59	-283	-55	743	1.0	748	1.0	
(9)	22.2	25.4 PU	0.2	37.5	.866	.1260	.716	.609	-320	-19	-37	-1	718	1.0	144	1.0	(b)
(10)	22.2	.203 PC	0.5	39.8	.839	.0792	.450	.393	-310	-20	-185	-20	740	1.0	814	1.0	(c)

Notes: "PC" = Polycarbonate
"PU" = Polyurethane foam
"X intercept" = Value of fluid parameter, [(Tfluid-Tamb)/I], for which collector efficiency = 0
"SI UNITS" = Standard International Units, deg C/(W/m2)
"ENGL UNITS" = English Units, deg F/(Btu/ft2/hr)

(a) Approximate conditions and dimensions for experimental stall sample, including I=913 W/m2 and rib thickness = .254 mm (.010 in). Losses, Grashof Numbers and Nusselt Numbers are stated for Tf = 78.6 C in this case. Kpolyurethane = .027 W/m/degC

(b) Same as Case 6 except copper absorber

(c) I=815.7 W/m2 for this case

Refer to Exhibit A in Appendix for details of each case study.

outdoor test of the fabricated collector model. These temperatures, values of insolation, wind velocity and ambient air temperature are shown in Table 2.

The ambient temperature (T_a), the stall temperature (T_p) and the insolation are used to calculate the stagnation intercept value,as follows:

$$\frac{T_p - T_a}{\text{Insolation}} = \text{Stall Intercept X}$$

Refer to Table 2, as well as Exhibit A in the Appendix, for the specific results of each defined condition.

2. Material Stress

(a). Hoop Stress

The hoop stress is calculated and plotted as shown in Figure X.

(b). Thermal Stress

Calculations of stress occurring at the absorber/ glazing interface during thermal shock, require the following simplifying assumptions:

- o Only one cell will be examined.
- o Temperature of the glazing will be uniform.
- o Temperature of the absorber will be uniform.
- o Final glazing temperature is equal to the water spray temperature of $50^{o}F$.
- o Final absorber temperature is equal to stagnation temperature (T_p).
- o The glazing cell is uniformly stressed longitudinally
- o The absorber material is uniformly stressed longitudinally
- o All thermal stress is transmitted to the bond area.

TABLE 2

STAGNATION TEST RESULTS *

DATE PERFORMED	TIME	PANEL BACKING	PANEL ORIENTATION	PANEL TILT (θ)	INCIDENT ANGLE (θ)	AVG. WIND VELOCITY (m/sec)	AMBIENT TEMP. (^{o}C)	INSOLATION (W/m^2)	MAX. STALL TEMP. (^{o}C)	X intercept ($^{o}C/(W/m^2)$)
9/28/79	14:57	Air	22^{o} West of South	25^{o}	28^{o}	0.5	39.8	815.7	100.7	0.075
9/28/79	13:21	Poly-urethane Foam (2.54cm thk)	22^{o} West of South	25^{o}	15^{o}	0.2	37.5	913.4	130.3	0.102
8/22/79	15:00	Corrugated Fiberglass (0.11 kg. with) (Foil)	22^{o} West of South	20^{o}	5^{o}	0.9 Gusts to 2.2	25.2	926.4	107.9	0.089
8/22/79	15:30	Plywood (1.27cm thk)	22^{o} West of South	20^{o}	8^{o}	0.9 Gusts to 2.2	25.8	891.7	95.2	0.078

* Refer to Figure IV for Panel Configuration Details.

ABSORBER HOOP STRESS

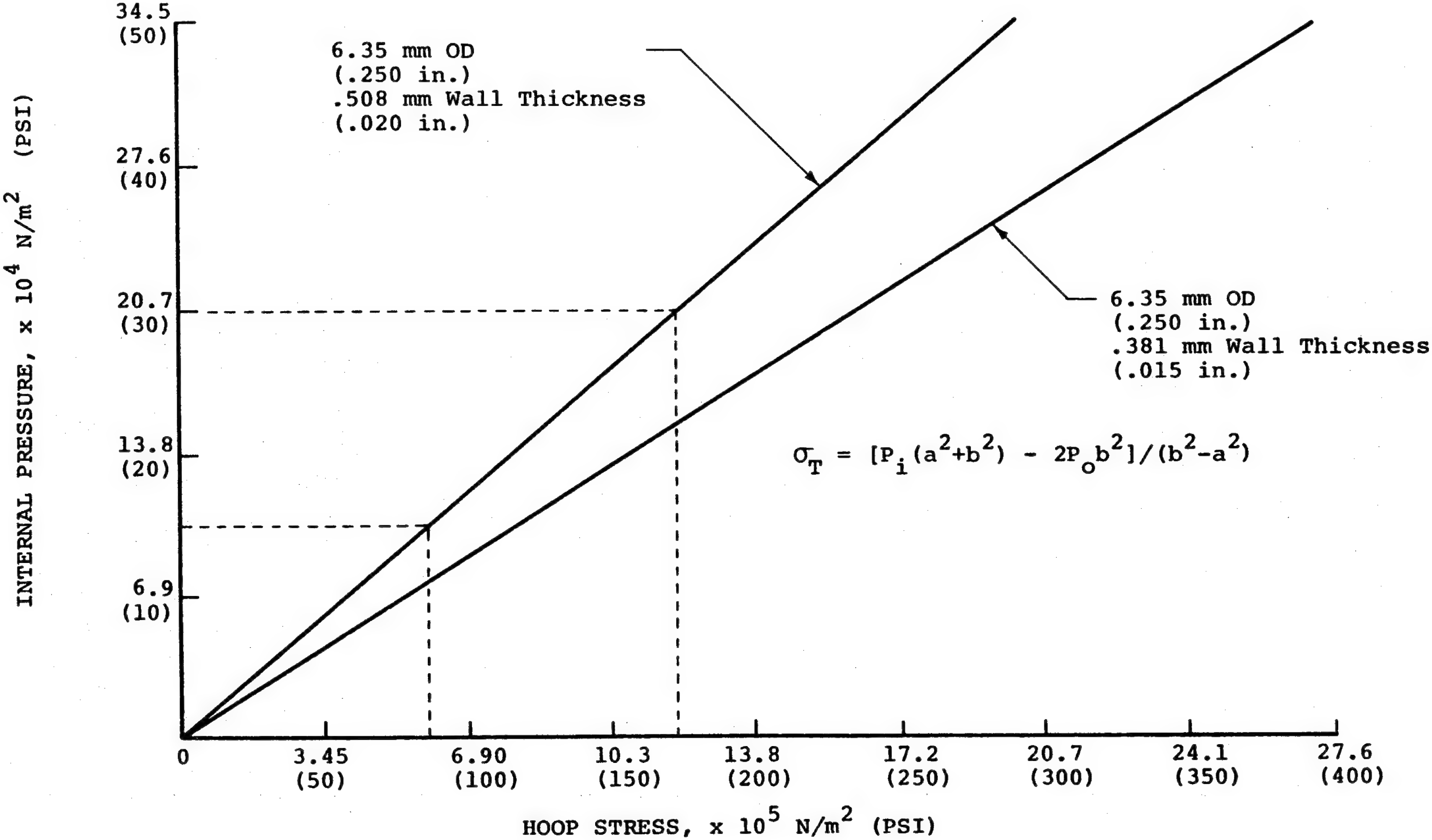
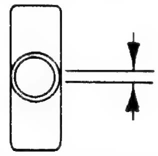


FIGURE X

o Cell dimensions are as follows:



Polycarbonate Rectangular Tube =
$0.875'' \times 0.266'' \times 0.008''$ wall thickness

Polyethersulfone(PES) Round Tube =
$0.250''$ O.D. x $0.020''$ wall thickness

Bond Width = $0.030''$

Length of Cell (L_o) = $115.0''$

o Cell temperature conditions are as follows:

$T_{ambient}(T_a) = 100^oF$

$T_{water\ spray}(T_w) = 50^oF$

$T_{manufactured}(T_m) = 75^oF$

$X_{cell} = 0.60\ ^oF\ BTU^{-1}ft^2hr$

$I = 300\ BTU/ft^2hr$

Calculations*:

A) The absorber stagnation temperature (T_p) can be determined

$$T_p = IX + T_a$$
$$= 300\ (0.60) + 100$$
$$T_p = 280^oF$$

B) Material cross-sectional area and bond area is calculated

$$\text{Rectangular area } (A_1) = 2(0.008)(0.266+0.875)$$
$$A_1 = 0.018\ in^2$$

$$\text{Round area } (A_2) = \pi\left[(0.250)^2-(0.250-0.040)^2\right]/4$$

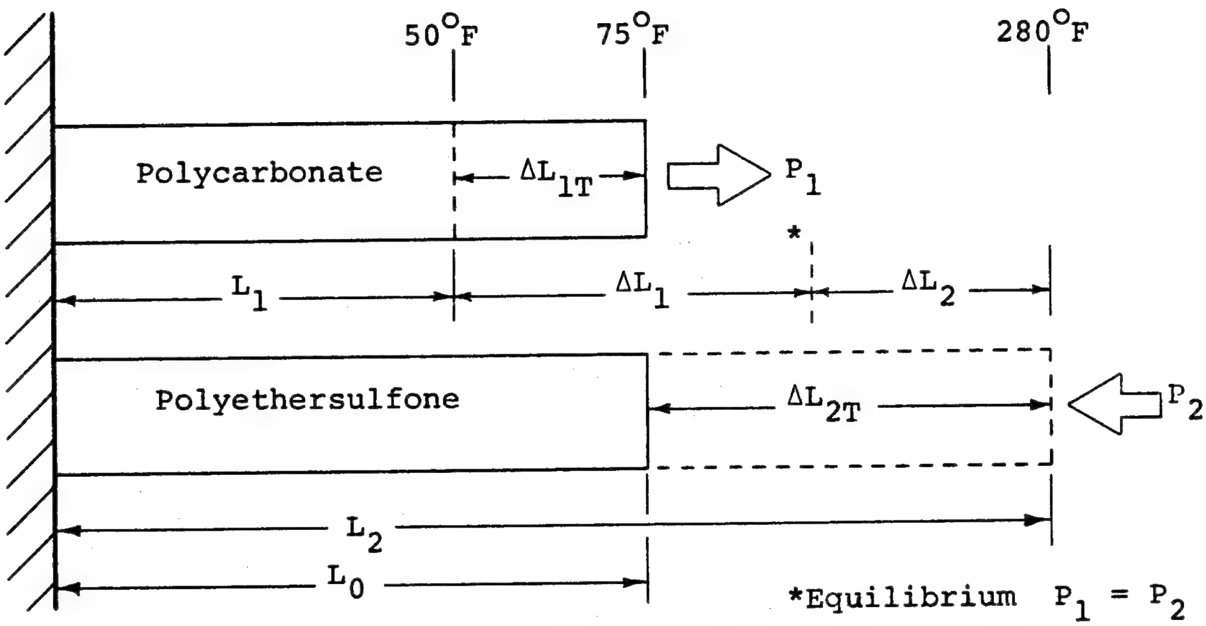
* Subscript (1) refers to polycarbonate(PC), and subscript (2) refers to polyethersulfone(PES).

$$A_2 = 0.014 \text{ in}^2$$

$$\text{Bond area } (A_b) = 2(115)(0.030)$$

$$A_b = 6.9 \text{ in}^2$$

C) The diagram shown below is used to calculate the stress resulting from thermal expansion of the coaxial composite



*Equilibrium $P_1 = P_2$

D) Calculate the unrestrained thermal expansion of both materials, using the equation

$$\Delta L = \alpha L_0 (\Delta T)$$

1) For polycarbonate at 50°F

$$\Delta L_{1T} = \alpha_1 L_0 (T_m - T_w)$$

where $\alpha_1 = 3.90 \times 10^{-5}$ in/in/°F

$$\therefore \Delta L_{1T} = (3.90 \times 10^{-5})(115)(75-50)$$

$$= 0.112 \text{ in}$$

2) For PES at 280°F

$$\Delta L_{2T} = \alpha_2 L_0 (T_p - T_m)$$

where $\alpha_2 = 3.06 \times 10^{-5}$ in/in/°F

$$\therefore \Delta L_{2T} = (3.06 \times 10^{-5})(115)(280-75)$$

$$= 0.721 \text{ in}$$

3) Final position of $PC(L_1)$ is determined by

$$L_1 = L_0 - \Delta L_{1T}$$
$$= 115 - 0.112$$
$$L_1 = 114.89 \text{ in}$$

4) Final position of $PES(L_2)$ is determined by

$$L_2 = L_0 + \Delta L_{2T}$$
$$= 115 + 0.721$$
$$L_2 = 115.72 \text{ in}$$

E) Determine the equilibrium position of both materials, assuming both ends are constrained by force (P) where

$$P = AE \frac{\Delta L}{L}$$

1) for $P_1 = P_2$

$$A_1E_1 \frac{\Delta L_1}{L_1} = A_2E_2 \frac{\Delta L_2}{L_2}$$

2) and

$$\Delta L_1 + \Delta L_2 = \Delta L_{1T} + \Delta L_{2T}$$
$$\Delta L_2 = \Delta L_{1T} + \Delta L_{2T} - \Delta L_1$$

3) substituting (2) into (1) and solving for ΔL_1 yields

$$\Delta L_1 = \frac{A_2E_2\left[\Delta L_{1T} + \Delta L_{2T}\right]}{L_2\left[\frac{A_1E_1}{L_1} + \frac{A_2E_2}{L_2}\right]}$$

where

$E_1 = 3.3 \times 10^5$ psi at $50^\circ F$

$E_2 = 3.1 \times 10^5$ psi at $280^\circ F$

$$\therefore \Delta L_1 = \frac{0.014(3.1 \times 10^5)[0.112 + 0.721]}{115.72\left[\frac{0.018(3.3 \times 10^5)}{114.89} + \frac{0.014(3.1 \times 10^5)}{115.72}\right]}$$

$$\Delta L_1 = 0.350 \text{ in}$$

4) solving for P_1 where

$$P_1 = A_1E_1 \frac{\Delta L_1}{L_1}$$

$$= \frac{0.018(3.3 \times 10^5)(0.350)}{114.89}$$

$$P_1 = 18.11 \text{ lbs.}$$

5) shear stress in the bond can be determined by

$$\tau = \frac{P_1}{A_b}$$

where A_b is the bond area in (B)

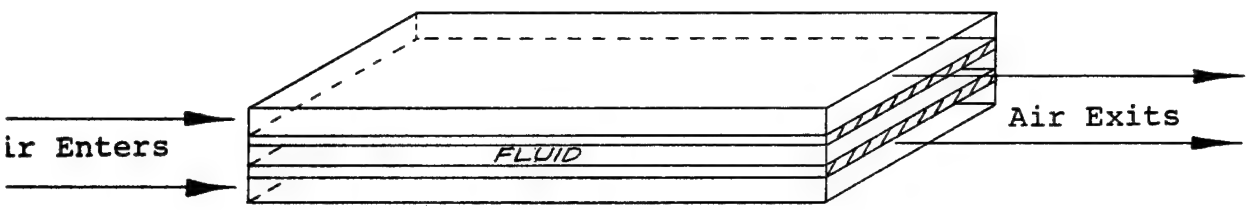
$$\therefore \tau = \frac{18.11 \text{ lbs.}}{6.9 \text{ in}^2}$$

$$\tau = 2.62 \text{ psi}$$

3. Water Diffusion and Condensation

Calculation of the air flow rate necessary to prevent condensation as well as the calculation of heat loss during this removal process, require the following simplifying assumptions:

- o Parallel plate composite



Height of Air Space = .3125 in.
Absorber Plate = .020 in. thick

- o Collector size = 48 in x 120 in
- o The glazing surface has a 0.5 mil coating (urethane or acrylic base), and is impermeable to water vapor.
- o Water vapor will be removed by air flow entering the glazing space at the bottom of the collector, and exiting at the top.
- o Temperature of the glazing and absorber is constant.
- o Vapor transmission by the absorber and air transport is constant.
- o Thermal conditions:

$T_{air\ in} = 40^oF$ (Dew Point Temperature)

$T_{air\ out} = 100^{o}F$ (50% Relative Humidity)

$T_{glazing} = 100^{o}F$

$T_{fluid} = 160^{o}F$

o **Water** vapor transmission of the absorber material(PES), as supplied by the manufacturer, is

$\dot{m}_w$ = 140.0 gm-mil/100 in^2/24 hrs
at $160^{o}F$ (100% Relative Humidity)

Calculations:

A) Water vapor transmission through the 20 mil plate

$\dot{m}_w$ = (140.0 gm-mil/100 in^2/24 hrs)/20 mil
= 7.0 gm/100in^2/24 hrs **

For one square foot collector area and unit conversion

$\dot{m}_w = 9.26 \times 10^{-4}$ lb H_2O/hr

B) Maximum moisture gain by air transport, at the assumed temperature conditions, is calculated using the following equations

$$\phi = \frac{P_v}{P_g} \qquad \omega = 0.622 \frac{P_v}{P-P_v}$$

where

ϕ = Relative Humidity
ω = Humidity Ratio
P_g = Saturation Pressure (psia)
P_v = Actual Vapor Pressure (psia)
P = 14.7 (psia)

** This transmission rate is a conservative estimate. A diffusion and porous flow analysis is not warranted for this study.

1) Moisture Content of Air Entering

$$T_{in} = 40^oF \text{ Dew Point}$$

$$\therefore P_{v1} = 0.1216 \text{ (psia)}$$

$$\omega_1 = 0.622(0.1216)/(14.7 - 0.1216)$$

$$\omega_1 = 5.19 \times 10^{-3} \text{ lb } H_2o/ \text{ lb air}$$

2) Moisture Content of Air Exiting

$$T_{out} = 100^oF \text{ (50\% Relative Humidity)}$$

$$\therefore P_{v2} = 0.50 \ (0.9492)$$

$$P_{v2} = 0.4746 \text{ (psia)}$$

and $\omega_2 = 0.622 \ (0.4746)/ \ (14.7 - 0.4746)$

$$\omega_2 = 2.08 \times 10^{-2} \text{ lb } H_2O/ \text{ lb air}$$

3) Maximum Moisture Gain (ω_{max})

$$\omega_{max} = \omega_2 - \omega_1$$

$$= (2.08 \times 10^{-2}) - (5.19 \times 10^{-3})$$

$$\therefore \omega_{max} = 1.56 \times 10^{-2} \text{ lb } H_2O/ \text{ lb air}$$

C) Air flow rate ($\dot{m}$) required to remove water vapor and prevent condensation on one surface, can be determined by

$$\dot{m}_a = \frac{\dot{m}_w}{\omega_{max}}$$

from(A and B)

$$\dot{m}_a = \frac{9.26 \times 10^{-4} \text{ lb } H_2O/hr}{1.56 \times 10^{-2} \text{ lb } H_2O/lb \text{ air}}$$

$$\dot{m}_a = 5.94 \times 10^{-2} \text{ lb air/hr}$$

and

$$\rho_{air} = 0.071 \text{ lb/ft}^3$$

Therefore, volumetric flow rate(Q) is determined by

$$Q = \frac{\dot{m}_a}{\rho_{air}}$$

$$= 5.94 \times 10^{-2}/0.071$$

$$Q = 0.836\ ft^3/hr$$

D) Collector heat loss ($\dot{q}$) is calculated using the following equation

$$\dot{q} = \dot{m}_a(h_{out}-h_{in})-\dot{m}_w h_w$$

where $h_{in} = 47.0$ BTU/lbm

$h_{out} = 15.2$ BTU/lbm

$h_w = 128.0$ BTU/lbm

from (A and C)

$$\dot{q} = (5.94 \times 10^{-2})(47.0 - 15.2)- (9.26 \times 10^{-4})(128.0)$$

Therefore, for one surface

$$\dot{q} = 1.77\ BTU/ft^2/hr$$

Total collector heat loss (upper and lower surfaces)

$$\dot{q}_T = 2(1.77)$$

$$\dot{q}_T = 3.54\ BTU/ft^2/hr$$

E) Air velocity (V) required to remove the moisture for a 40 ft^2 collector can be determined by

$$Q = AV$$

where Q = Volumetric flow rate of the air

and A = Transport area

1) from C) $Q = 0.836\ ft^3/hr$ for 1 ft^2 collector

$$Q_{40} = 0.836\ (40)$$

$$Q_{40} = 33.4\ ft^3/hr$$

and

2) $$A = (0.3125)(48)$$

$$= 15\ in^2$$

$$A = 0.104\ ft^2$$

3) Therefore,

$$V = \frac{33.4\ ft^3/hr}{0.104\ ft^2}$$

$$= 320.6\ ft/hr$$

$$V = 1.07\ in/sec$$

B. Materials Search

Absorber Material

Table 3 summarizes the desired and actual properties of absorber materials.

The desired continuous use temperature, determined by the computer simulation, is 155°C. Most materials in the absorber matrix, however, have an upper continuous use temperature limit of 100°C to 120°C. The sulfone family offers significantly higher temperature performance than do the other materials. Other potential materials which are suitable for high temperature applications are fluoropolymers and polyphenylene sulfides. The following is an evaluation of these materials.

Fluoropolymers:

Fluoropolymers are difficult to extrude and very costly. The standard nitrided extruder barrels are damaged by fluoropolymers. As a result, special fabricated barrels and screws are required. In addition, fluoropolymers have shown poor compatibility with other polymers.

Polyphenylene Sulfides:

Polyphenylene sulfides are non-extrudable at the present time.

Sulfones:

Polysulfone is the leading candidate material for the absorber, because of its over-all chemical and physical properties. Polyethersulfone has superior thermal and tensile properties, as compared to polysulfone, but its higher cost eliminates it as the leading candidate for use as an absorber material.

Glazing Material

Table 4 summarizes the desired and actual properties of glazing materials.

Materials in the glazing matrix having poor UV stability and high cost, are eliminated from consideration, leaving the following:

TABLE 3

ABSORBER MATERIALS

	DESIRED PROPERTIES	POLYPHENYLENE SULFIDE	POLYPROPYLENE	ACETAL	THERMOPLASTIC POLYESTERS	POLYPHYLENE OXIDE	POLYCARBONATE	POLYSULFONE	POLYETHER-SULFONE	FLUOROPOLYMER
STRUCTURE		Amorphous	Crystalline	Crystalline	Crystalline	Amorphous	Amorphous	Amorphous	Amorphous	Amorphous
CO-EXTRUDES TO:		Amorphous	Polyolefins	Acetals	Polyesters	Most Amorphous	Amorphous	Amorphous	Amorphous	Amorphous
UV RESISTANCE	Fair/Good	Fair	Fair	Fair	Good	Good	Good	Fair	Fair	Good
HOT WATER RESIST	Good	Good	Good	Good	Poor	Good	Poor	Good	Good	Good
HEAT DISTORT TEMP AT .455 MN/m^2 °C	150	260	88	158	115/188	149	135	181	204	160
UL CONTINUOUS USE TEMP, °C	155	170	95/115	105	110	95/125	115	150	180	180
THERMAL COEFF. OF EXPANSION, cm/cm °C	Compatible w/Glazing	$2x10^{-5}$	$16.2x10^{-5}$	$11.9x10^{-5}$	$11.9x10^{-5}$	$5.9x10^{-5}$	$7.0x10^{-5}$	$5.6x10^{-5}$	$5.5x10^{-5}$	$5.4x10^{-5}$
THERMAL CONDUCTIVITY, $cal/sec \cdot cm^2 \cdot$ °C	$3x10^{-4}$	$6.8x10^{-4}$	$3x10^{-4}$	$6x10^{-4}$	$7x10^{-4}$	$5x10^{-5}$	$5x10^{-5}$	$3x10^{-4}$	$4x10^{-4}$	$6x10^{-4}$
TENSILE STRENGTH, MN/m^2	60.0	69.0	26.9	60.7	55.2	75.9	62.1	70.4	82.8	44.9
EXTRUDABILITY	Good	Poor	Good	Fair	Poor	Good	Good	Good	Good	Fair
MANUFACTURERS	Various	Phillips Petro.	Various	Celanese, DuPont	Various	G.E.	Mobay, G.E.	Union Carbide	ICI	Dupont
PRICE, $/kg	$6.61/8.81	$6.61	$0.88	$2.11	$3.53	$3.53	$3.31	$8.81	$22.60	$18.74

(8/79)

TABLE 4

GLAZING MATERIALS

	DESIRED PROPERTIES	ACRYLIC	CELLULOSICS	AMORPHOUS NYLON	POLYCARBONATE	POLYARYLATE
STRUCTURE		Amorphous	Crystalline	Amorphous	Amorphous	Amorphous
CO-EXTRUDES TO:		Amorphous	Various	Amorphous	Amorphous	Amorphous
LIGHT TRANSMISSIVITY %@.254mm THK	90	92	88	88	91	90@.127mm thk
UV RESISTANCE	Good	Excellent	Fair	Poor	Good	Good
HEAT DISTORT TEMP AT .455 MN/m^2	125	79-107	49-93	135	135	190@1.69MN/m^2
UL CONT USE TEMP, °C	120	80	80-100	120	120	120-130
THERMAL COEFF OF EXPANSION, cm/cm °C	Compatible with Absorber	$7.4x10^{-5}$	$7.0x10^{-5}$	$7.0x10^{-5}$	$7.0x10^{-5}$	$7.7x10^{-5}$
THERMAL CONDUCTIVITY, cal/sec·cm^2·°C		$6x10^{-4}$	$8x10^{-4}$	$5x10^{-4}$	$5x10^{-4}$	$5x10^{-4}$
TENSILE STRENGTH, MN/m^2	>60.0	48.3-75.9	13.8-53.8	73.8	62.1	65.6
IMPACT STRENGTH, J/m	>500	10.7-122.8	53.4-530.4	53.4-267.0	640.8-961.2	224.3
EXTRUDABILITY	Good	Fair	Fair	Good	Good	Good
MANUFACTURERS	Various	Various	Various	Union Carbide	Mobay, G.E.	Union Carbide
PRICE, $/kg	$4.41	$1.32	$1.76	$13.67	$3.31	$5.40

(8/79)

Acrylic:

Of all the glazing materials, acrylic offers the highest light transmissivity and UV resistance. Its extrudability is fair. However, its continuous use temperature is 80°C, far below the required level, and its low impact strength of 10.7 to 122.8 J/m makes it undesirable for outdoor use.

Polyarylate:

Polyarylate has a low initial impact strength, and is higher in cost than polycarbonate. It is yellow in color and, therefore, its aesthetic value is low. Transmissivity is lower than polycarbonate, although with thin walls thermal performance will not be significantly affected.

Polycarbonate:

On the basis of overall properties and cost, polycarbonate is the leading candidate glazing material.

C. Materials Evaluation

1. Accelerated Environmental Exposure

The graphs and tables applicable to this section are displayed as Exhibit B in the Appendix.

(a). Polysulfone

In order to make polysulfone test samples, it is compounded by the manufacturer, using a single screw lab extruder. The material is processed by the extruder twice. The material produced is P1700 with 2.5 wt.% Vulcan 9 Carbon Black and 0.5 wt. % Zinc Oxide, as recommended by the vendor for this outdoor application. The compound is extruded as a 0.508 mm sheet. The surface of the sheet appears rough, due to poor dispersion of the filler. This indicates that polysulfone has poor "wettability" with fillers.

Polysulfone is also compounded as above with the addition of 10% and 20%, by weight, fiberglass.

This results in a 0.508 mm extruded sheet which exhibits pinholes throughout the material. The pinholes make the material unacceptable for further testing.

Initial elongation of polysulfone, without carbon black is 60%. The initial elongation of the carbon black filled test samples is 6%, which approaches the limits of the tensile tester, resulting in the following:

- UV Aging

  No measurable change is observed after 2000 hours of exposure.

- EMMAQUA

  No measurable change is observed after 800,000 Langleys.

- Thermal Aging

  No measurable change is observed after 1000 hours of exposure.

- Steam Testing

  All samples stressed at $.69 MN/m^2$ and $1.38 MN/m^2$ levels, at 120°C steam, fail within one week of exposure in the chamber. The failure is due to stress cracking. Consequently, tensile testing is not performed.

  It is possible that in addition to the applied stress, the residual stress resulting from processing produces stress cracking in the material. To investigate this possibility, samples are stress-relieved in a 150°C oven for 24 hours, and resubmitted to the same stress conditions at 120°C steam. All of these samples fail within two weeks of exposure.

- Chemical Testing

  No measurable change is observed after 20 weeks exposure.

(b). Polyethersulfone

The polyethersulfone 300P sample is compounded with 2.0% Vulcan P Carbon Black. The 0.508 mm sheet appears smooth. Unlike polysulfone, the polyethersulfone is ductile. The tensile tests with Carbon Black show an initial elongation of 90%.

o UV Aging

UV aging shows a drop of elongation to 26% within 1000 hours.

o EMMAQUA

EMMAQUA shows a drop of elongation to 38% at 400,000 Langleys.

o Thermal Aging

Polyethersulfone is subject to degradation in a thermal oxidative environment. The tensile elongation drops to 10%, after 200 hours aging in a 200°C oven.

o Steam Testing

Polyethersulfone is subject to deterioration upon exposure to a high temperature water environment. This is evident by a drop in elongation to 7%, after one week aging in 100°C and 120°C steam and 1.38MN/m^2 stress.

o Chemical Testing

Polyethersulfone is exposed to a chlorine solution of 50 ppm, a copper solution of 25 ppm and an ethylene glycol solution of 100%. After 8 weeks of chlorine exposure at an elevated temperature of 75°C, the polyethersulfone demonstrates a drop in elongation to 49%. In the copper a drop to 27% occurs. And, in the ethylene glycol, a drop of elongation to 47% occurs.

(c). Polycarbonate

Samples of 0.127 mm to 0.254 mm thicknesses are supplied by the manufacturer. The initial elongation

is 110%. The initial transmissivity is 91%.

Without Coating

- UV Aging

  UV aging shows a drop in elongation to 7% within 200 hours of exposure.

- EMMAQUA

  EMMAQUA exposure demonstrates a drop in elongation to 32% at 200,000 Langleys. Surface erosion of polycarbonate is evident by a weight loss of 11%, after 400,000 Langleys in the laminate series. In addition, transmissivity drops to 64%.

- Thermal Aging

  After 1000 hours exposure at 120°C, the polycarbonate demonstrates a drop in elongation to 41%, with insignificant loss of transmissivity.

- Steam Testing

  After one week of exposure at 100°C saturated steam, the polycarbonate demonstrates a drop in elongation to 4%, a reduction in transmissivity to 88% and material failure within 2 weeks.

With Coating

- UV Aging

  In the laminate series UV aging,at 4000 hours, produces a drop in elongation to 6% and an insignificant drop in transmissivity, when coated with KL-1-1063. When coated with LS 123, the polycarbonate again demonstrates a drop in elongation to 6%.

- EMMAQUA

  In the laminate series EMMAQUA exposure at 400,000 Langleys produces a drop in elongation

to 46% and a drop of transmissivity to 89%, when coated with KL-1-1063. In addition, the weight loss is approximately 3%. When coated with LS 123, at the same exposure, elongation drops to 5% and transmissivity to 81%, with a weight loss of 3%.

(d). Polyarylate(without coating)

Samples of 0.127 mm thickness are used for these tests. The initial elongation is 50%. The initial transmissivity is 89%.

o UV Aging

UV aging at 2000 hours exposure produces a drop in elongation to 32%, with no change in transmissivity.

o EMMAQUA

An exposure of 400,000 Langleys in the laminate series, produces a drop in elongation to 10%, reduction in transmissivity to 86% and a weight loss of 6.5%.

2. Non-Accelerated Environmental Exposure

(a). UV Screening of Coatings

Results are seen in Exhibit C of the Appendix. Examination reveals a sharp "cut-off" of UV radiation at 400 nm for both the coated and uncoated glazings.

(b). Thermal Shock Resistance of Coatings

The LS 123 coating shows no signs of peeling or cracking after 20 cycles.

D. Preliminary Processing Tests

1. Moisture Absorption

Due to the hygroscopic nature of all the candidate materials, each must be dried prior to melt processing. The following is a listing of the manufacturers' recommendations.

Material	Actual Moisture Content	Drying Time/ Temperature
Polycarbonate	Less than 0.01%	6 hours at 121^{o}C
Polysulfone	Less than 0.05%	2 hours at 163^{o}C; 3½ hours at 135^{o}C
Polyether-sulfone	Less than 0.05%	3 hours at 177^{o}C to 193^{o}C 6 hours at 143^{o}C to 182^{o}C

Moisture does not hydrolyze the polysulfones, or in any way react with them to cause permanent discoloration, chemical degradation or deterioration. Material containing moisture can be re-ground, dried and extruded witout loss of original properties.

The maximum relative moisture content permitted in the material is 10% for polyethersulfone and 20% for polycarbonate. (Note: "Relative moisture content" used in this research is not to be confused with actual moisture content, as published in materials literature and as indicated above. Moisture content is used here on a comparative basis only, and is determined as shown in the methods and procedures section.)

Experimental results show a maximum melt processing time of 30 minutes for polyethersulfone and polycarbonate, after initial extrusion. (Refer to Figure XI.) Water cooling processes during extrusion may increase this moisture absorption rate. Therefore, confirmation of these curves is obtained during the single extrusion experiments.

2. Melt Behavior

The melt viscosity of polycarbonate, polysulfone and

WATER ABSORPTION OF
POLYETHERSULFONE AND POLYCARBONATE
AT 20°C, 85% RELATIVE HUMIDITY

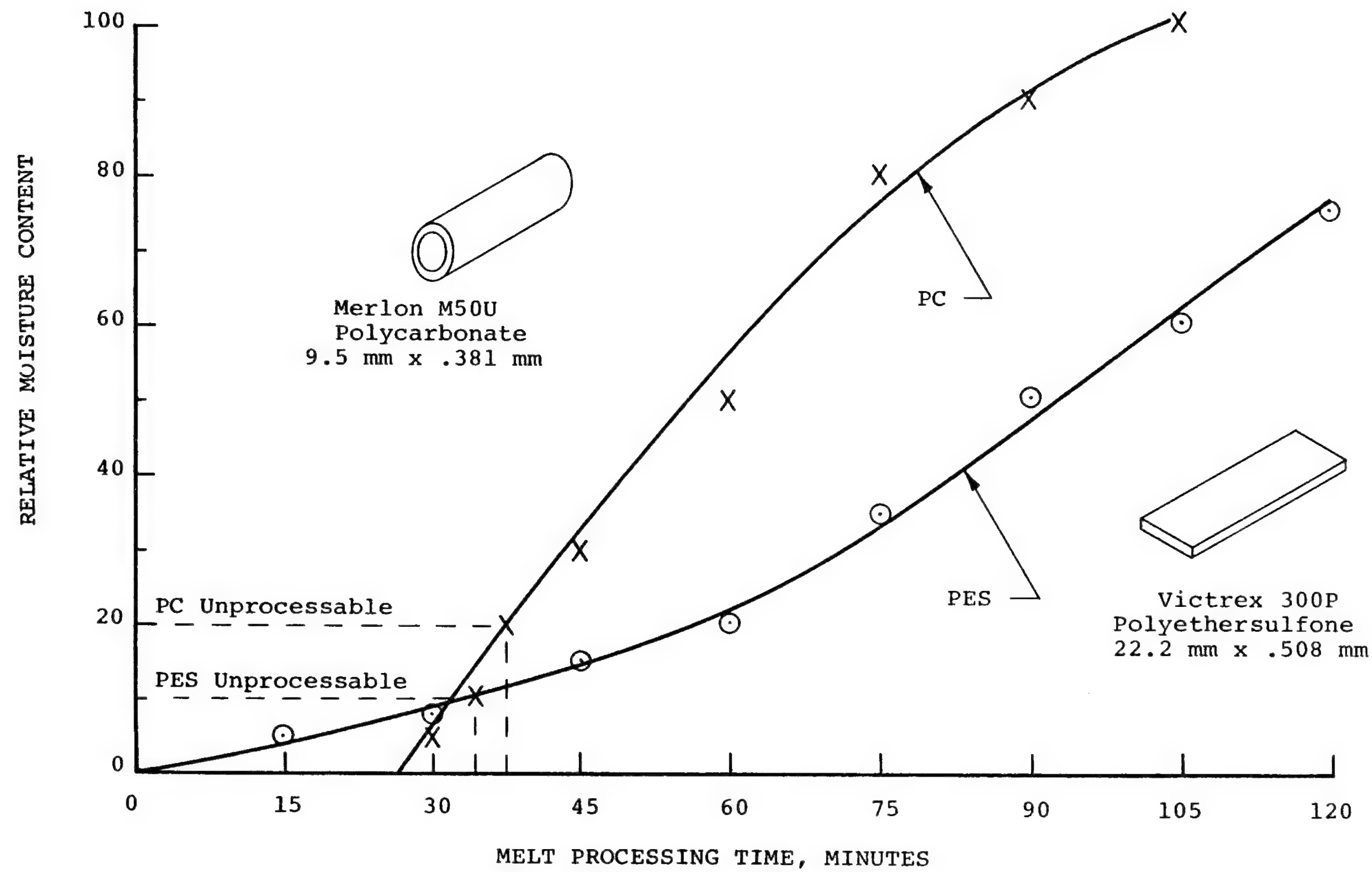


FIGURE XI

polyethersulfone are relatively insensitive to shear rate, as compared to polyolefins. At the high shear rates encountered in the extrusion equipment, the candidate materials have a higher viscosity at optimum processing temperatures. With increasing shear rates, viscosity of the polyolefins decreases more rapidly than for the candidate materials. This can be explained by the broader molecular weight distribution and lower molecular weight of polyolefins as compared to the candidate materials. Molecular weight differences also result in less die swell for the candidate materials, permitting lower die draw-down ratios. This produces a more consistent profile extrusion, lower shrinkage and better dimensional stability.

Polyethersulfone, polysulfone and polycarbonate have similar temperature-sensitive melt viscosities and require a narrower working range in barrel and die temperatures than polyolefins.

It is, therefore, concluded that the extrusion of candidate materials will require highly accurate temperature controllers, die and screw design modifications and greater extruder power.

3. Weldability

The bond between polycarbonate and polyethersulfone is investigated. The polysulfone is not investigated because of its stress-cracking tendencies.

Polyethersulfone has a higher viscosity and melting point than polycarbonate. Therefore, problems arise when melt-forming the materials in combination. If processing temperatures are high, to accommodate the polyethersulfone, the polycarbonate can experience thermal deterioration.

Several common techniques are used in an attempt to bond polycarbonate and polyethersulfone. The techniques include the use of a hot air welder, radiant heat,

focusing IR heaters and preheated platens. All trials produce poor bonding.

However, one significant bond test does produce substantial adhesion. Polyethersulfone resin is melted on a hot platen in the shape of a rectangle. A temperature of $300^{o}C$ to $315^{o}C$ is maintained. Three 0.127 to 0.254 mm thick strips of polycarbonate are then laid into the melted resin. The strips quickly melt, and are left undisturbed for five minutes. A polycarbonate round tube is laid on this surface. The sample is immediately cooled in water. An intermixing of the polymers does not occur, but excellent adhesion is obtained. The resulting specimen shape prevents tensile testing.

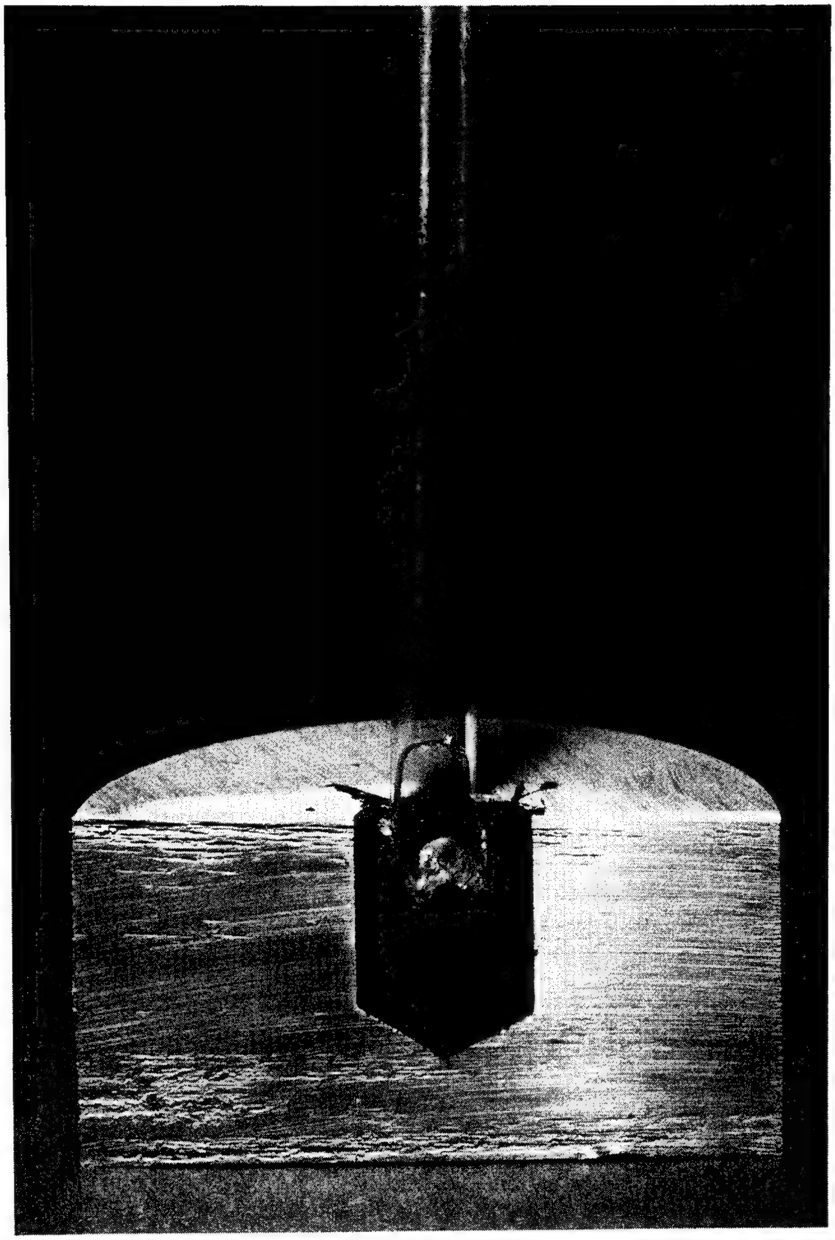
4. Miscibility

Melt Blending

Melt blending is performed in an aluminum mold having a chamber 25.4 mm in depth and 12.7 mm in diameter, and filled with polyethersulfone granules. The mold is slowly elevated to a temperature of approximately $320^{o}C$, and held there for 20 minutes, until the polyethersulfone has completely melted. A cover on the chamber distributes the heat evenly. The cover is then removed and a 6.35 mm diameter polycarbonate tube is slowly lowered into the molten polyethersulfone. No heat is added; the heat from the higher melting polyethersulfone evenly melts the polycarbonate, as it is fed into the polyethersulfone. The two materials do not blend. A well defined line marks the boundary conditions between the two polymers. A tensile strength of approximately 6.20 MN/m^2 is determined for the bond. (Refer to photograph on next page.)

Flange Formation

After the panel is coaxially extruded, part of the glazing may be trimmed back to 76.2 to 102 mm, so that a flange can be formed. This process requires a melting



MELT BLENDING
(POLYCARBONATE/POLYETHERSULFONE)

together of polyethersulfone and polycarbonate, due to the polycarbonate residue between the tubes.

The materials are dried completely, prior to processing. A round coaxial tube composite is fed into a die. The die is water-quenched internally, preventing water absorption by the materials. A flange is formed successfully, although sticking occurs as a result of the shrinkage of material during cooling. Porosity and striations in the flange also occur , as shown in the photograph. The high melt temperatures required for forming polyethersulfone cause degradation of the polycarbonate. Blending is not successful, but a flange is formed.

E. Processing Experiments

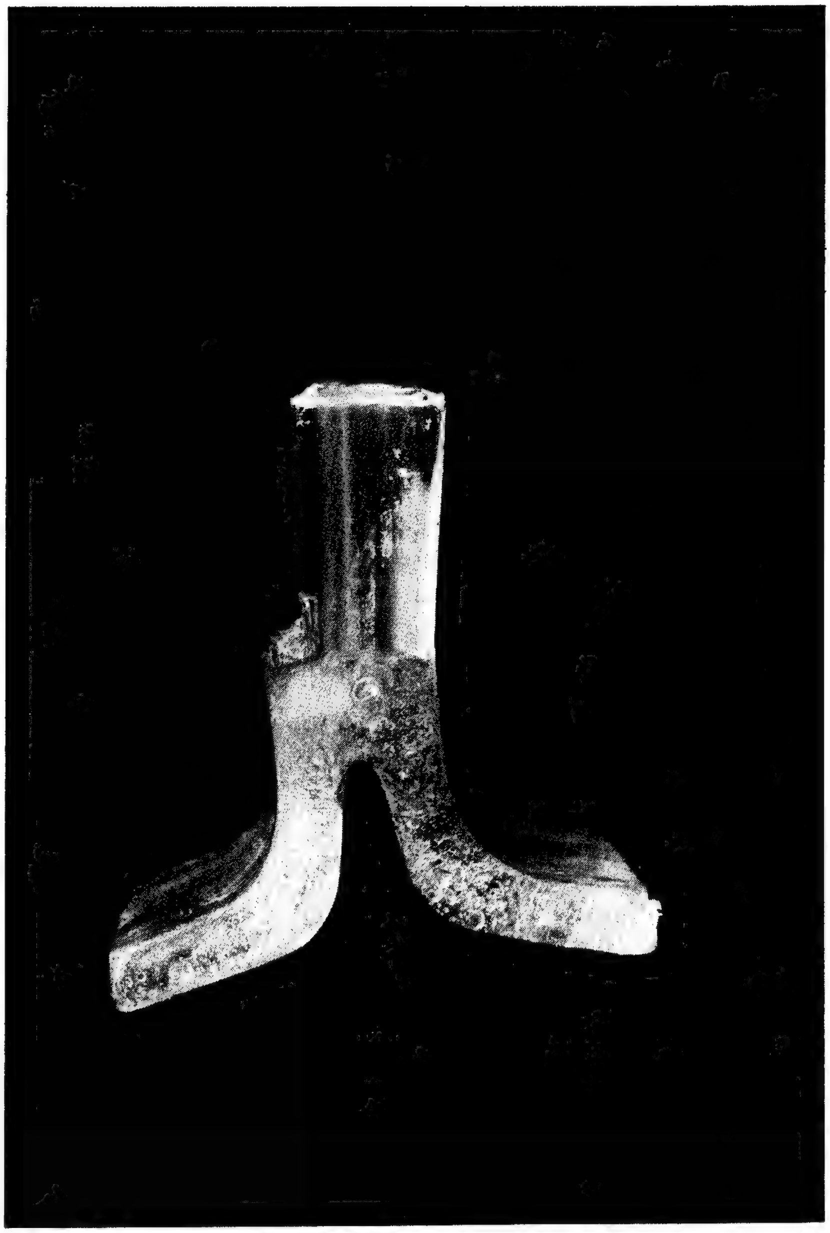
1. Preliminary Extrusion

The processing of candidate materials require modifications to the existing FAFCO extrusion equipment. These modifications are as follows:

Barrel and die temperatures are expected to be up to 370^{o}C for the processing of materials. Therefore, West Temperature Controllers are installed, each having a maximum temperature range from room temperature to 426.6^{o}C. Due to the high viscosity of the candidate materials, a cooling mode is included on 5 of the 7 purchased controllers.

An available 9.906 mm die and 6.35 mm tip are installed on a 6.35 cm, 24 to 1 Davis Standard Extruder. An existing extruder screw, having a 4 to 1 compression ratio, and an L/D ratio of 24 to 1, is used for this portion of the processing experiment.

An existing water cooling trough is modified in order to evaluate various cooling methods. These modifications permit the extrudate to travel through a variable "air gap" (10.16 cm to 914.40 cm) before entering the water cooling trough. This allows the material to pass its glass transition point, prior to



FORMED FLANGE
(POLYCARBONATE/POLYETHERSULFONE)

making contact with water. Within the air gap, a manifold is constructed such that air blowers can provide cooling of the extrudate. The blower air temperature can be adjusted from ambient air temperature to 315°C. This allows the tubing temperatures to be reduced in stages.

The distance the tubing is submerged in water can be varied from 0.305 to 6.096 meters. These air/water cooling variables enable a determination of the effect of cooling on the polymers' properties.

An existing Capstan assembly is modified in order to prevent distortion and damage to the thin-walled, round polycarbonate tubing.

Heaters are installed on the hopper and resin storage bins, minimizing moisture absorption by the resins.

Polycarbonate:

Merlon M50U polycarbonate resin is used for the polycarbonate extrusion runs.

The resin is pre-dried for 6 hours at 120°C, in a Thoreson-McCosh dessicant drier.

Polycarbonate is extruded using the temperature profiles and conditions shown in Table 5.

The high viscosity of polycarbonate requires substantially higher input power per revolution than existing polyolefins. The Davis Standard Extruder is equipped with a 40 hp motor, and a maximum current rating of 60 amps. Due to the high gear ratio of the extruder and high motor current, the experiments are limited to low screw rotation rates (20 rpm at 55 amps input). This, in turn, limits material output to 0.610 m/sec. A lower gear ratio can be used in the future to obtain higher material output.

The melt strength of the polycarbonate is excellent. Round tubing is extruded with consistent 0.254 mm wall thickness, and 6.35 mm outside diameter. This results

TABLE 5

EXTRUSION PARAMETERS

Tube Configuration	Polycarbonate	Polysulfone	Polyethersulfone	Polycarbonate	Co-Extrusion
	Round	Round	Round (D102)	Rectangular (D101)	Rectangular (D103)
Barrel Size	6.35cm(2.5 in.)	6.35cm(2.5 in.)	1.9cm(0.75 in.)	1.9cm(0.75 in.)	1.9cm(0.75 in.)
Profile Temp. 1	260°C (500°F)	316°C (600°F)	300°C (572°F)	282°C (540°F)	282°C (540°F)
2	271°C (520°F)	327°C (620°F)	340°C (644°F)	288°C (550°F)	288°C (550°F)
3	282°C (540°F)	338°C (640°F)	350°C (662 °F)	288°C (550°F)	288°C (550°F)
4	265°C (510°F)	343°C (650°F)			
5	260°C (500°F)	349°C (660°F)			
Die Temp. 1	232°C (450°F)	316°C (600°F)	>360°C (680°F)	282°C (540°F)	>293°C (560°F)
2	238°C (460°F)	327°C (620°F)			
Screen Pack	20/40/40/20 mesh	20/40/40/20 mesh	None	20/40/60/80 mesh	20/40/60/80 mesh
Screw RPM	20	30	18.5	18.5	18.5
Amperes	55	50	-	-	-
H.P.	40	40	3/4	3/4	3/4
Head Pressure	20.7-24.2 MN/m^2 (3000-3500 psi)	13.8 MN/m^2 (2000 psi)	13.8 MN/m^2 (2000 psi)	24.2 MN/m^2 (3500 psi)	26.2 MN/m^2 (3800 psi)
Line Speed	0.61 m/sec (2 ft/sec)	0.91 m/sec (3 ft/sec)	0.02 m/sec (4 ft/min)	0.027 m/sec (5.25 ft/min)	0.027 m/sec (5.25 ft/min)
Air Pressure (Internal)	1494-1993 N/m^2 (5-8 in. H_2O)	747.2 N/m^2 (3 in. H_2O)	Atmospheric	Atmospheric	Atmospheric
Vacuum Tank Pressure	Atmospheric	Atmospheric	20,318 N/m^2 (6 in. Hg)	3,386.4 N/m^2 (1 in. Hg)	3,386.4 N/m^2 (1 in. Hg)
Cooling	Air/Open Water Trough	Air/Open Water Trough	Water Vacuum Tank	Water Vacuum Tank	Water Vacuum Tank
O.D.	0.610-0.711 cm (0.240-0.280 in.)	0.635 cm (0.250 in.)	0.648 cm (0.255 in.)	2.22 x 0.635cm (0.875x0.250in.)	2.22 x 0.635 cm (0.875x0.250 in.)
Wall Thickness	0.0356-0.254 mm (0.014-0.010 in.)	0.508 mm (0.020 in.)	0.508 mm (0.020 in.)	0.1524 mm (0.006 in.)	0.1524 mm (0.006 in.)
Wall Drawdown Ratio	7.0	3.5	1.3	1.6	1.6

in a wall thickness draw-down of 7.0. The wall is successfully run as thin as 0.200 mm, resulting in a draw-down of 8.8. The maximum consistent outside diameter is 9.5 mm. Water cooling is determined to be superior to that of air, for ease of material handling and consistency of shape.

The die and barrel temperatures are varied, in order to evaluate the shear sensitivity of the polycarbonate resin. The results of these variations indicate that polycarbonate has a wide processing range, and is an excellent material with which to work - approaching the facility of polyolefins.

Polysulfone:

The Udel P-1700 polysulfone resin is compounded with 2.5% Carbon Black and 0.5% Zinc Oxide, and predried for 4 hours at 135°C in a Thoreson-McCosh dessicant drier.

Polysulfone is extruded using the temperature profiles and conditions shown in the Extrusion Parameter Table (Table 5).

Material is extruded at a rate of 0.91 m/sec. The tubing diameter is 6.35 mm and the wall thickness is 0.508 mm, resulting in a wall thickness draw-down of 3.5. The melt strength of the material is superior to that of polycarbonate.

Tubing surfaces are rough, as a result of poor dispersion of Carbon Black. This was also observed during the extrusion of samples for the Materials Evaluation portion of this study.

The tubing is very brittle. Slight bending, in a radius of less than 15 cm, causes the tubing to crack and break, indicating that the material is notch-sensitive and susceptible to stress-cracking.

2. Single (non-coaxial) Extrusion

Extrusion dies are designed and built in order to produce the materials in conformance with Figures

VII, VIII and IX. The dies are described on the following two pages (Figures XII and XIII).

The following conditions are found to be in common for both the polyethersulfone and polycarbonate extrusions.

- o The extruder utilizes a 19 mm barrel with an L/D ratio of 25 to 1. Gear ratios permit the use of 3/4 hp motor at 18.5 screw rpm.
- o A two-stage screw.
- o No screen pack is installed; a spacer ring is used.
- o A vacuum sizing tank with sizing rings is used. The gap from the trough to the head of the die can be varied from 16 to 216 mm.
- o The throat of the extruder is water-cooled for consistent resin temperature.
- o Various die temperatures are used; the final configuration incorporates two 250-volt, 650-Watt, 38 mm heaters.

Polyethersulfone:

For the polyethersulfone extrusion, Victrex 300P polyethersulfone, with 0.5% Carbon Black content, is purchased. It is dried according to the manufacturer's recommendations.

The feed zone temperatures are set at 300°C, 340°C and 350°C. The die and adapter are held at 360°C.

The die tip is 6.35 mm in diameter, with a land length of 19 mm. The die is 7.7 mm in diameter, with a land length of approximately 19 mm. (Figure XII)

At a back pressure of 13.8 MN/m^2, the output is 0.02 m/sec.

The optimum wall thickness draw-down is 1.3. The melt strength is excellent.

The vacuum sizing tank, which is 0.61 meters long, is placed 215 mm away from the die. The extrusion conforms to the specified tolerances. The wall

ROUND TUBING DIE AND TIP

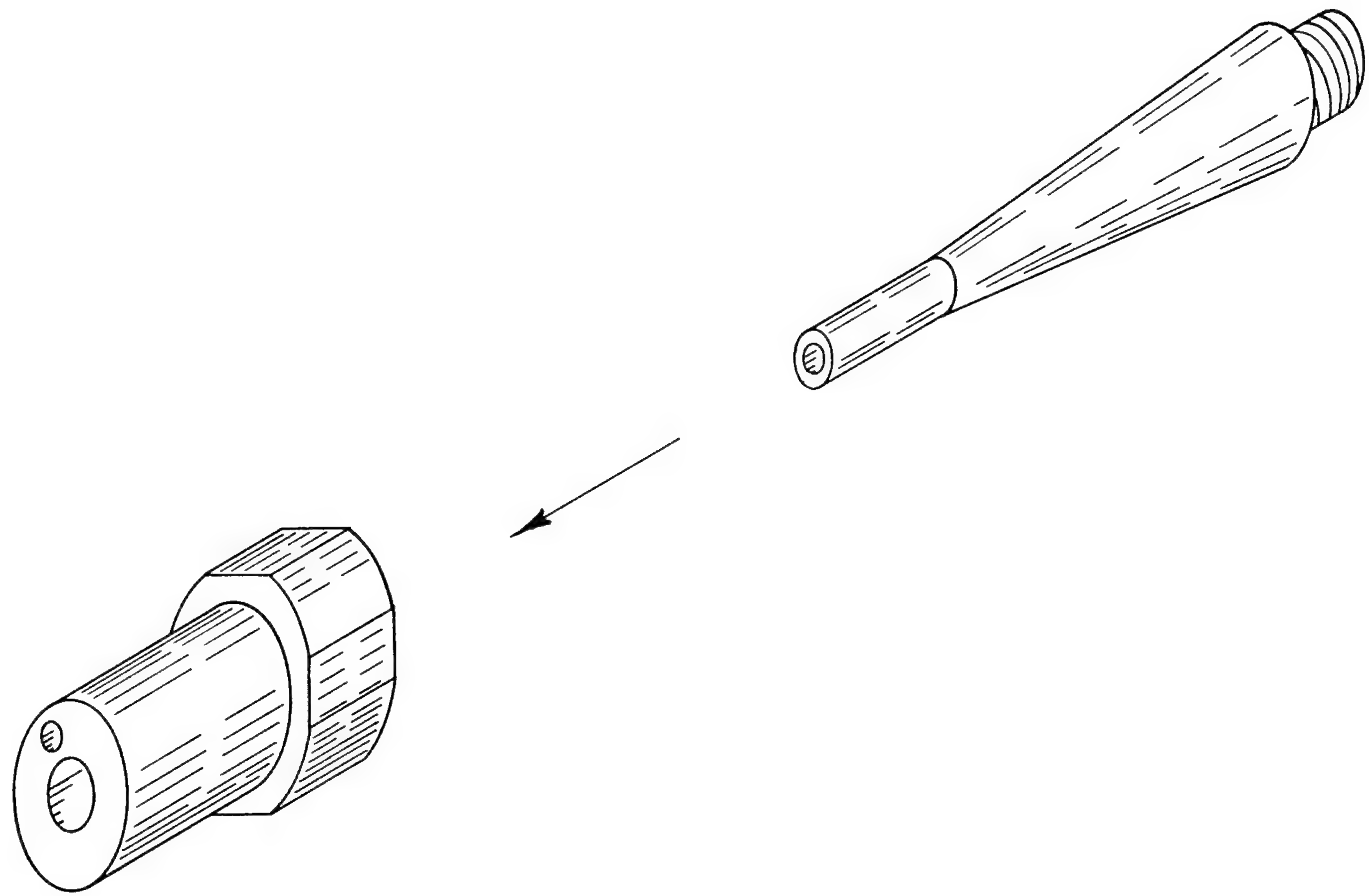


FIGURE XII

COAXIAL EXTRUSION DIE

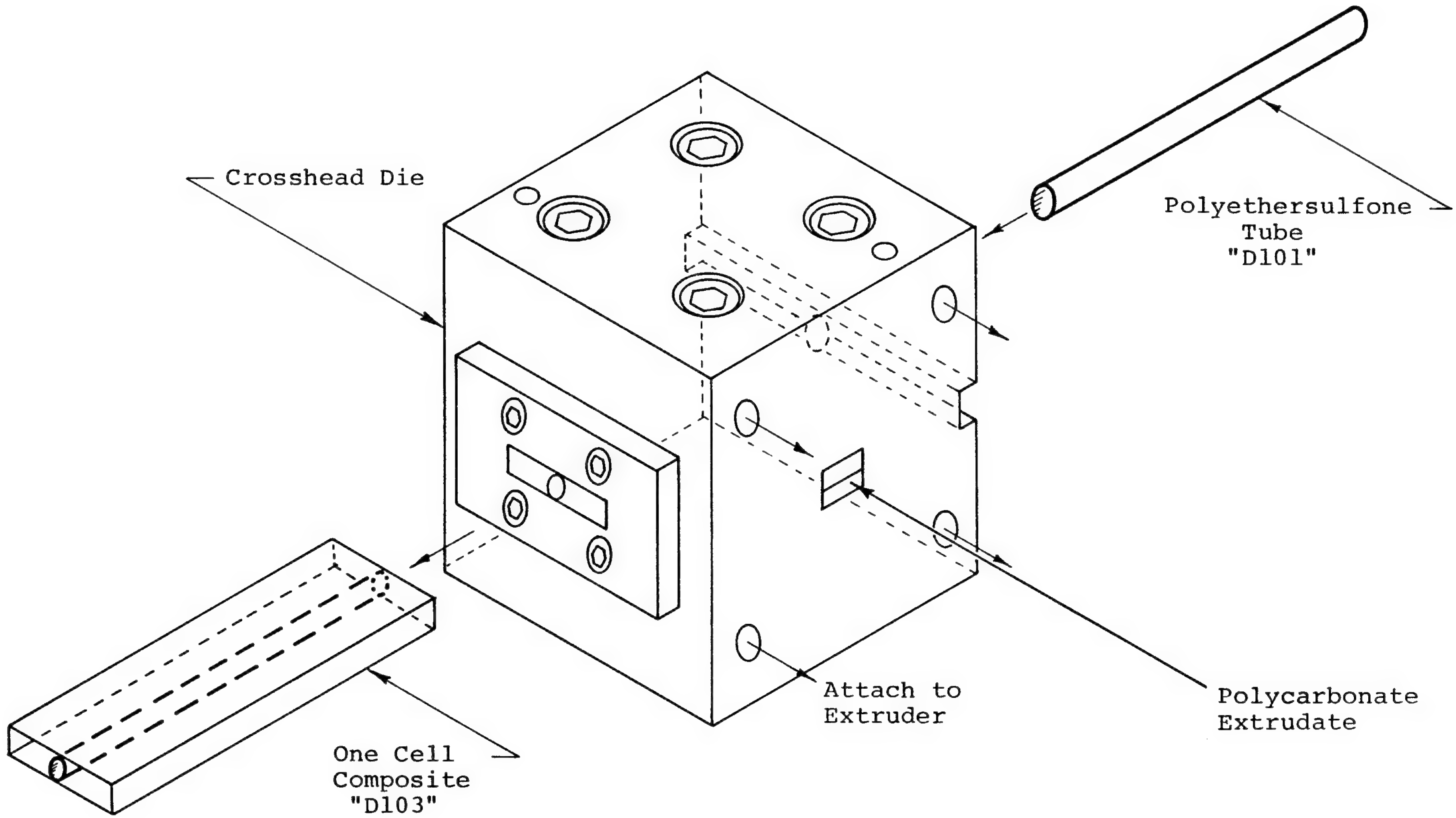


FIGURE XIII

thickness varies by 0.127 mm. When the vacuum is increased to 24.13 cm of Hg, at a gap of 15.9 mm, very fine chatter marks are produced. More chatter marks are present at thin wall sections than at thick wall sections. The 95.25 mm die gap is optimum, with a vacuum of 15.24 cm of Hg.

The vacuum tank sizing section measures 45.72 cm in length. The sizing rings are progressively spaced from 0.05 cm to 7.0 cm to avoid harmonics. However, chattering on the outer surface still results. When the length of the sizing section is decreased and the water temperature is increased from 15.6°C to 29.4°C, the chatter marks are improved to acceptable levels. The entrance to the vacuum sizing tank requires a non-chamferd face for consistency in tubing size.

Approximately 250 meters of tubing is extruded. (Figure VIII) One hundred fifty meters of this material has an excellent high gloss surface; the remainder has slight chatter marks, but is still useable for the coaxial extrusion.

After extrusion, corrosion of the high quality tool steel is observed in the die. Additionally, the silver solder is stripped away. Polyethersulfone at 360°C appears to be corrosive. To prevent this, special tooling materials will be required.

Difficulty with the resin is encountered due to the insufficient chopping by the manufacturer. Normally, thin needle-like granules are furnished, varying in length from 6.35 to 7.94 mm. The resin received contained granules of up to 38 mm in length, which interfered with the functioning of the small experimental feed hopper.

<u>Polycarbonate</u>:

The polycarbonate is dried for 10 hours at 120°C. It is extruded through a cross-head die (Figure XIII) to produce rectangular tubing, as specified in Figure VII. The same extrusion equipment is used for this

extrusion as was used in the polyethersulfone extrusion. A 9.3 cm long sizing section is used in the vacuum tank.

A rectangular profile is produced to specifications. One wall of the rectangular section is observed to fold inward, caused by heat from the extruder barrel migrating to the cross-head die. This results in a higher temperature on one side of the die than the other. Die temperatures are readjusted to minimize this problem.

Wave-like warpage of the tubing, in the longitudinal direction, is also observed, and believed to be caused by non-uniform cooling of the extrudate in the vacuum sizing tank. The material is extruded with the shorter dimension vertical. The shorter sides cool first, causing "buckling" in the longer surface. This problem is minimized by annealing.

After exiting the vacuum sizing tank, samples of the polycarbonate tube are subjected to the moisture absorption tests. The relative moisture content at 30 and 60 minute intervals is 10% and 60%, respectively. This indicates a negligible effect of vacuum tank sizing on water absorption. (Refer to Figure XI.)

The quality of the extrusion is excellent and, with minor die adjustments, wall thicknesses are held consistent between 0.152 and 0.178 mm.

3. Coaxial Extrusion

The rectangular tubing is extruded over the previously extruded absorber material,utilizing the cross-head die (Figure XIII), resulting in the coaxial configuration.

Four foot diameter polyethersulfone coils are placed in a drying unit, averaging 150°C for 17 hours, prior to extrusion.

During the drying process, cracking and breaking occurs. However, five 6 meter segments were available for further testing.

The polyethersulfone is fed through a 15 cm air preheater prior to entering the cross-head die. Upon entering the die, the polycarbonate back pressure increases substantially - due to the cooling of the die caused by the tubing. The die temperature has to be increased by 12^{o}C to compensate. As the two materials exit the die, they are brought into contact and a light bond is achieved, having sufficient strength to pull the polyethersulfone through the cross-head die. The bond is not acceptable, however, since slight flexing causes failure.

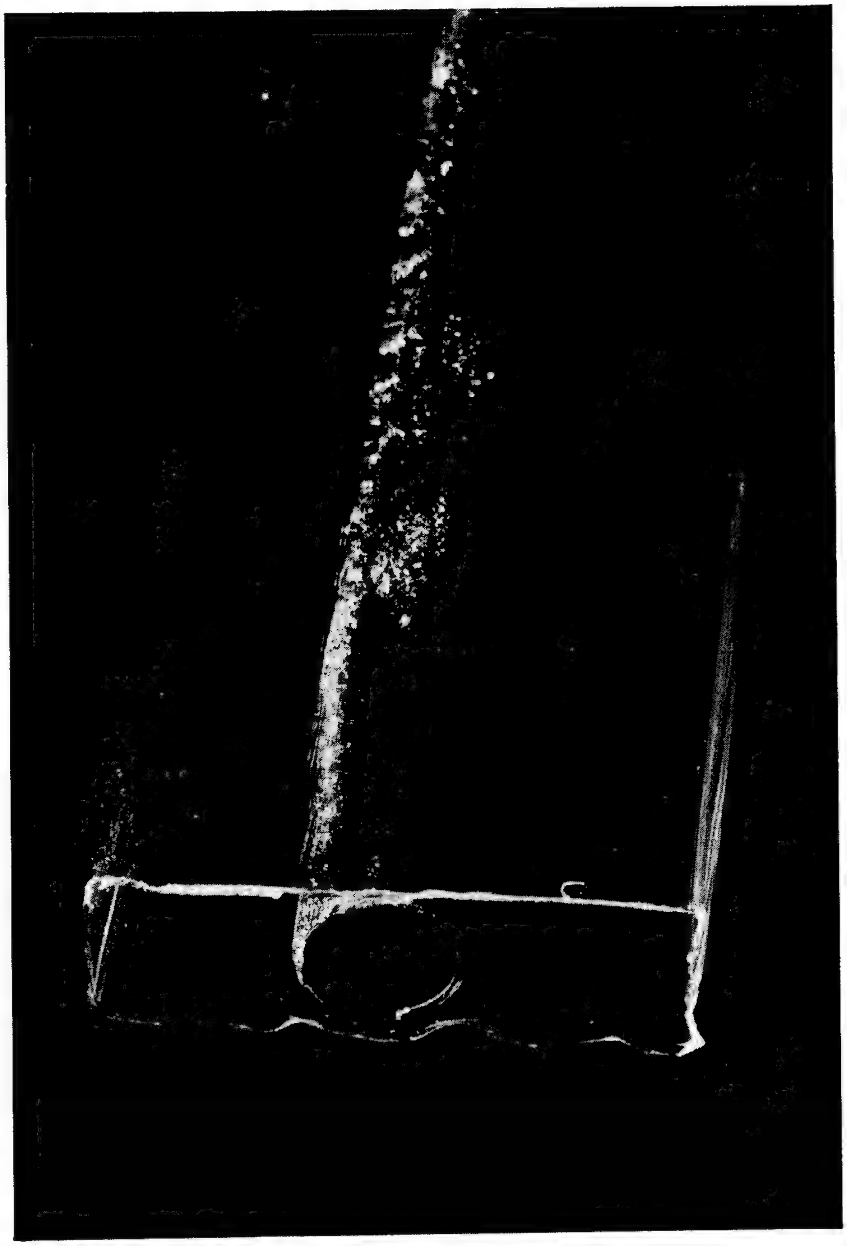
A satisfactory bond is obtained by melting the surface of the polyethersulfone prior to entering the cross-head die.

Approximately 14 meters of the coaxial extrusion is obtained. (Refer to photograph on next page.)

F. Cost Evaluation

Cost estimates of various collector profiles are tabulated. (Refer to Table 6.) Manufacturing cost is calculated, and can be compared for various materials.

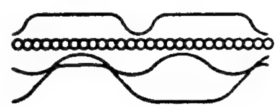
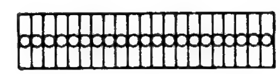
FAFCO Coax 1 uses polysulfone as an absorber, whereas FAFCO Coax 2 uses polyethersulfone. The comparison of polysulfone ($30.35/m^2) to polyethersulfone ($51.13/m^2) demonstrates a considerable cost differential, due primarily to the cost of the resin. For this collector configuration to be cost effective, the manufacturing cost has to range between $32.00 to $43.00 per square meter. Therefore, the potential for use of polyethersulfone in this configuration is marginal.



COAXIAL EXTRUSION
(POLYCARBONATE/POLYETHERSULFONE)

TABLE 6

COST ESTIMATE OF VARIOUS COLLECTOR PROFILES

Collector	FAFCO Pool	FAFCO IV	FAFCO Coax 1 (1)	FAFCO Coax 2 (1)	Typical
Glazing Material	None	Fiberglass	Polycarbonate	Polycarbonate	Glass
Absorber Material	Polyolefin	Polyolefin	Polysulfone	Polyethersulfone	Copper
Type	Unglazed	Single Glazed	Single Glazed	Single Glazed	Single Glazed
Configuration					
X intercept ($^{o}C/(W/m^2)$)	0.046	0.067	0.106	0.106	0.102
Useful Area (m^2)	3.53	3.17	3.58	3.58	2.95
Direct Materials ($\$/m^2$)	3.23	24.65	30.35	51.13	49.84

(8/79)

(1) Polyurethane Insulation Not Included.

DISCUSSION

The objective of this study was to develop a process for direct conversion of inexpensive raw materials into a completed solar collector unit, without labor intensive assembly operations. It was thought that materials carefully matched to the process and "end-use" environment would substantially reduce collector costs, as compared to conventional industry practice.

With this objective in mind, the feasibility of developing an extrudable coaxial configuration was studied. The coaxial configuration, which used two materials, was necessary because no single material had all the required physical properties to meet the total operational needs of the collector. The glazing material required a high degree of transparency and UV resistance, while the absorber material required compatibility with hot water and high temperatures. Extrusion was emphasized in the study because it was a low cost processing method.

Cellular construction, which was basic to the coaxial configuration, had several benefits: strength (glazing material had many supports), good thermal performance and low cost.

In order to begin the research and achieve the stated goals, it was necessary to make certain basic assumptions. These assumptions were based upon established minimum operating standards for collectors.

The maximum internal pressure of the collector was chosen to be .207 MN/m^2. Since the pressure drop across a collector is .007 MN/m^2, good system design will result in adequate fluid flow with a maximum operating pressure of .069 MN/m^2. Therefore, it was felt that the .207 MN/m^2 was more than sufficient for most system applications.

In large collector systems, adequate fluid flow in each collector was important for efficiency. The collector head loss curve had been developed for swimming pool collectors. It assured good flow distribution in large collector banks. Flow variation in collectors in large solar banks was less than 40%

for banks containing 12 collectors, if end-fed, and 17 collectors, if diagonally fed.

Life expectancy was specified as 15 years. The collector was designed symmetrically, with glazing on both sides, so that it could be turned over to double the life expectancy of the glazing material and improve thermal performance.

Once the assumed standards were established, a computer simulation was run to investigate the effect of design parameters on collector performance. The first area of interest in the computer simulation was the thickness of the collector (height of the cell) and its effect on thermal performance. Computer cases 1 through 3 investigated this effect. Increasing the height of the cell by 33% (from 19.1 mm to 25.4 mm), increased the X intercept by 9% (from 0.0842 to 0.0920 $^{o}C/(W/m^{2})$). This indicated that the X intercept was very sensitive to the cell height and was a useful design variable. The X intercept response to cell height appeared to be linear at the values investigated. Consequently, the impact on performance by even thicker cell sections should be investigated.

Cases 4 and 5 investigated the effect of insulation on the panel performance. The cell structure on the back of the panel was not adequate in itself to give good performance. However, a 12.7 mm of urethane, added to the basic panel configuration, made a substantial improvement by increasing the X intercept 51%. An additional 12.7 mm of urethane provided an additional increase of 6% in performance.

Cases 7 and 8 demonstrated that wind velocity had a very important affect on collector performance. An increase in velocity from 0 to 2.2 meters/second decreased the X intercept by 23%. If wind speed was increased up to 4.5 meters/second, there was an additional decrease of 10% in the X intercept.

Thermal conductivity of the absorber materials can affect collector thermal performance, and was investigated in cases 6 and 9. Case 6 was for a plastic absorber material and case 9 was for copper; both materials having a 0.718 mm wall thickness.

The conductivity of these two materials was markedly different. The conductivity of the copper was roughly 2000 times that of the plastic. Use of the polysulfone, in this instance, decreased efficiency by only 2.5%. This demonstrated that absorber material conductivity did not significantly affect thermal efficiency because (a). the relatively poor conductivity of the plastic material was offset by the thin wall (less than 0.718 mm); (b). the collector surface was fully wetted (there was no fin to degrade thermal performance); and, (c). the radiation was diffuse, resulting in low levels of heat flow. For example, at typical expected insolation values impinging on a 0.508 mm thick polysulfone surface, the approximately 775 Watt/m^2 of thermal energy collected by the surface resulted in a 3.4^{o}C temperature drop across the surface. This temperature did not decrease collector thermal performance more than a few percentage points.

Absorber stagnation temperature was determined from case 6, as shown in Exhibit A of the Appendix. The calculations for expected temperatures of the absorber material were developed for typical environmental conditions, including an insolation of 913 Watts/m^2 and an ambient temperature of 37.5^{o}C. The minimum continuous use temperature required by absorber material was then set equal to this calculated temperature of 155^{o}C. Continuous use temperature normally assumes a life of 60,000 hours for materials exposed to this temperature. It is a useful criterion for solar collector material selection, and should be equal to or exceed the stagnation temperature. Assuming stagnation conditions exist for a maximum of 6 hours per day, and 90 days per year, a material life of 60,000 hours assures a minimum solar collector life of 15 years.

The glazing temperatures were also established in case 6, as shown in Exhibit A of the Appendix. The temperature at the surface of the glazing was determined to be 99^{o}C, and approached 153^{o}C near the absorber. Due to the fact that there was a temperature gradient in the glazing material, and that the greatest material strength was required at the surface, a

representative continuous use temperature of 120°C was chosen. This temperature was considered to be more than adequate for most operating conditions.

In order to confirm the computer model and evaluate materials for use in the collector, an actual collector sample was fabricated and stagnation tested for comparison with the computer run. The computer model was verified for two cases: the uninsulated case (case 10 of the computer model) , and the insulated case (case 6 of the computer model).

Agreement between the X intercepts, calculated from the fabricated model test results, verified the computer model. Case 10 corresponded within 5% of the actual test.

The insulated,fabricated model test results were compared with case 6. Agreement was within 19%. The cause of the difference was believed to be primarily loss of heat at the edges of the test model. Essentially, this was due to the small size of the fabricated model (.09 square meter),and the difficulty of insulating the edges of that model. Evidence of the edge loss was seen in the thermocouple measurements during the test. Three thermocouples were positioned 7.6 cm apart, and the center thermocouple was observed to be from 3 to 4 degrees higher in temperature than the outside thermocouples for each test. This indicated heat flow from the center of the panel configuration out toward the edges. Another effect believed to be a cause of the discrepancy was air leakage through the glazing due to the difficulty of obtaining adequate sealing of the channel ends. In addition it was difficult to specify the K-value of the urethane used in the fabricated model. According to vendor information, as the temperature of urethane increases, the K-value also increases by about 5%; with aging, the K-value of the urethane can increase up to 48% in 36 months. Consequently, it was difficult to determine precisely the insulation value of the urethane to use in the computer model experiment. As shown by the computer model, the X intercept was very sensitive to insulation. More accurate results in the future could be obtained by using a larger fabricated model

and an alternate insulation material. However, the results of this research demonstrate the validity of the computer model, especially for investigating this collector configuration.

Hoop stress was investigated to determine the thickness requirements of the absorber material in the coaxial configuration. Thickness was an important design criteria. As thickness became greater, the hoop stress of the material became less. However, since greater thickness meant more material, the total cost of the entire configuration increased.

In this study, material hoop stress was limited to no more than 2 per cent of the tensile strength of the material. These hoop stress values were chosen in order to limit the amount of "creep" during the life of the panel. (As applied to this research, creep is the total strain occurring in a material after prolonged exposure to temperature and stress.)

Thermal stress, in the coaxial configuration, caused by rapid cooling, was calculated for worst case conditions. Assumptions made for these calculations were believed to be conservative in that they assumed conditions much more severe than would be encountered during normal operation. Stress was calculated to be no greater than $1.8 \times 10^4 N/m^2$. This was substantially below the actual material tensile strength which was estimated to be approximately $70.4 \times 10^6 N/m^2$. Consequently, stress resulting from thermal shock testing was not a reason for concern.

Water condensation, which could impair the thermal performance of the collector, must be avoided. Water which diffuses through the absorber wall into the space between the glazing and the absorber must be removed before it reaches 100 per cent relative humidity. It was found from the calculations that the velocities of air flow required to remove the moisture were small (less than 2.7 cm/sec). This air flow will result in negligible heat loss (less than one percent of the normal collected energy), and can be supplied by natural convection.

The materials evaluation for the glazing indicated that polycarbonate was the preferred material. The problems with the material in the uncoated state were primarily loss of transmissivity. Specifically, transmissivity dropped by 27% after 400,000 Langleys of EMMAQUA exposure. For this reason a coating for the material was necessary. Tests with the KL1-1063 coating on polycarbonate improved performance significantly. A 2% loss in transmissivity occurred after 400,000 Langleys exposure. Further work should be conducted with surface coatings, specifically to reduce the UV cut-off wavelength to further protect the glazing and absorber materials under it. The coating must be easy to apply during collector manufacture, and must withstand 15 years of outdoor exposure.

Polyarylate was also evaluated and performed well. Transmissivity only dropped 3% after 400,000 Langleys exposure. Cost was significantly higher, however, than polycarbonate.

The evaluation of candidate absorber materials did not lead to a material which met the requirements. Polysulfone was the prime candidate, chosen for its good thermal properties, low cost and expected compatibility with water. However, problems were encountered unexpectedly with brittleness and stress cracking during steam testing. The addition of Carbon Black filler required for resistance to UV radiation substantially increased brittleness. The brittleness resulted in such low values of tensile elongation (below 6%) that testing results were ambiguous because they approached the measurement limits of the tensile tester.

The stress cracking tendencies in a steam environment were unexpected because they far exceeded the material vendor's (Union Carbide) results, in which the material had been exposed to a 150°C steam environment, while stressed at 4.14 MN/m^2 for 200 hours, without failure. Samples tested at FAFCO, at 120°C and 1.38 MN/m^2 stress, failed within 2 days. The discrepancy was believed to result from the different samples used. The FAFCO

samples were thinner, measuring 0.508 mm instead of 2.54 mm, and were exposed to steam on both sides, rather than on a single side, as in the Union Carbide research. Stress cracking in hot water is a surface phenomenon, explaining the more rapid failure in the FAFCO tests. The thin samples were believed to be more representative of actual material performance in the coaxial configuration.

As a result of the above indicated problems, polysulfone was disqualified as a candidate material. In response to this situation, the polysulfone experiments were redesigned, and some of the planned long-term exposure tests were cancelled. At the same time a greater emphasis was put on polyethersulfone as the primary candidate. Additional tests were initiated. However, since the accelerated exposure required more time than was available in the research contract, some of the data on polyethersulfone was incomplete.

The properties of polyethersulfone were found to be superior to those of polysulfone. The initial elongation of polyethersulfone was 90%, rather than the 6% of the polysulfone. The continuous use temperature was 180^{o}C, rather than 150^{o}C. However, problems were also encountered with polyethersulfone. Stress cracking in a steam environment occurred, although less severely than with polysulfone. In addition, elongation dropped from 90% to 7%, after one week of exposure. Cost was high. Therefore, polyethersulfone was also disqualified.

Melt behavior of polycarbonate and polyethersulfone was investigated; both materials were found to be well suited for extrusion. Their viscosities were adequately close to permit processing together in the coaxial configuration.

Polysulfone was not evaluated for weldability due to the stress cracking results. Attempts to bond materials by heating surfaces to the melt point and then bringing them into contact, were not successful with polycarbonate and polyethersulfone, showing that bonding of those materials after extrusion may not be possible.

The miscibility tests did result in successful bonding of melted materials. Polyethersulfone had a higher melt temperature

than polycarbonate. Consequently, molten polyethersulfone can be used to melt a polycarbonate sample. When cooled, a good bond results, with tensile strength of at least 6.21 MN/m^2. This verified that during extrusion the two materials could be bonded while in the molten state, to form a multiple cell coextrusion configuration.

Flange forming, which is necessary to bond the panel body to the manifold, was also successfully demonstrated. It was shown that polycarbonate and polyethersulfone materials can be formed into a flange.

The extrusion of polyethersulfone was successful, although the material was brittle and, therefore, required extreme care in handling.

The extrusion of a polycarbonate profile, with walls less than 0.4 mm, had not been accomplished prior to this project. A thin walled (0.15 mm to 0.20 mm), rectangular profile of polycarbonate material was successfully extruded in this research,demonstrating feasibility as a production method. Temperature uniformity in the die was found to be extremely critical, and should be investigated further.

A single cell coaxial configuration was also successfully extruded. Good bonding between the glazing and the absorber required pre-melting of the polyethersulfone surface as it was fed into the die. The resulting configuration presented a good bond and met the specifications.

Scaling up the coextrusion process for production of wide, multiple cell,coaxial configurations is believed to be possible. However, an absorber material which met the requirements, especially compatibility with hot water, was not available at the time the study was conducted. Consequently, it is recommended that research and development of the coaxial configuration be continued when a suitable absorber material becomes available.

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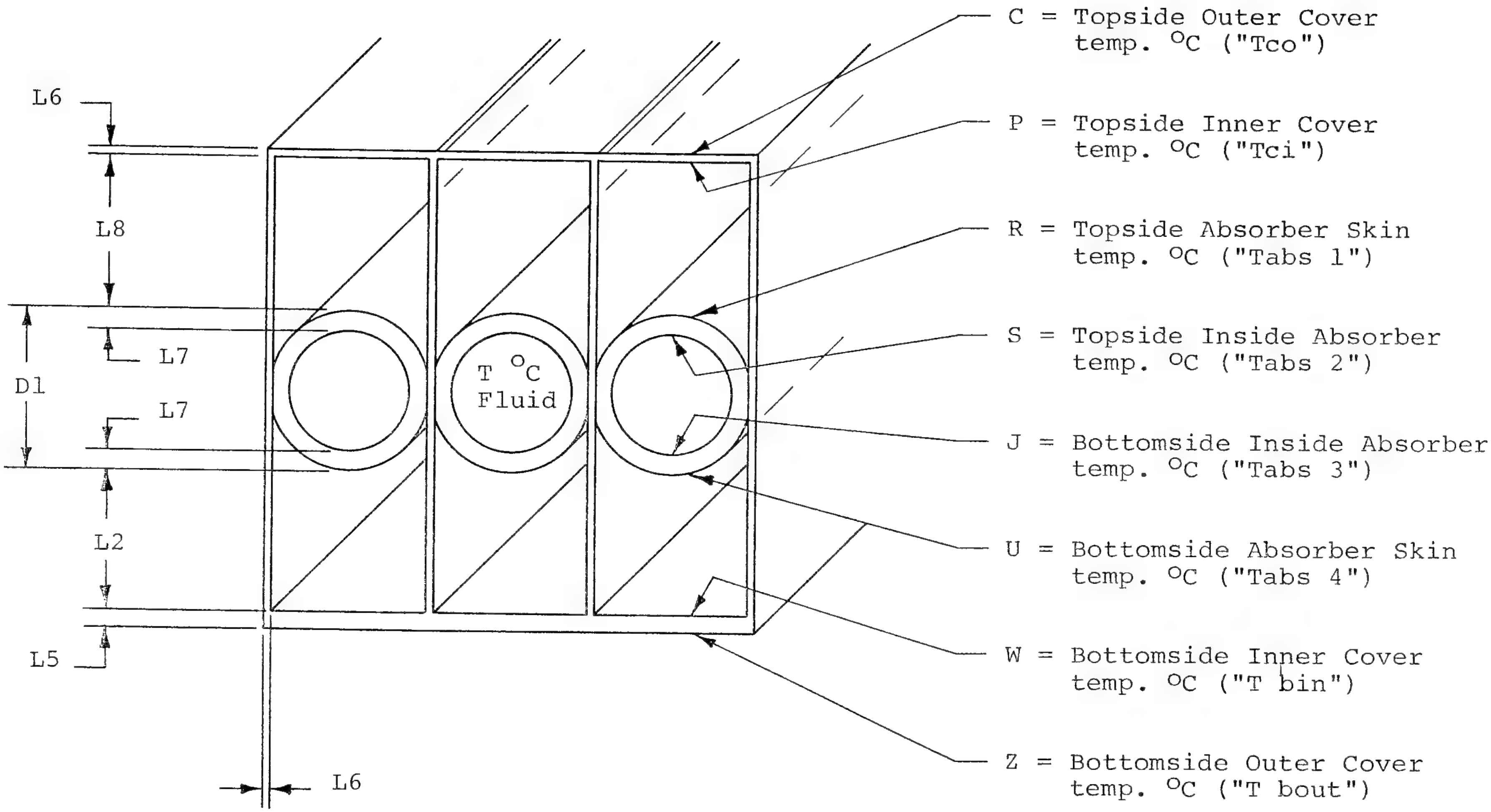
COAXIAL COLLECTOR

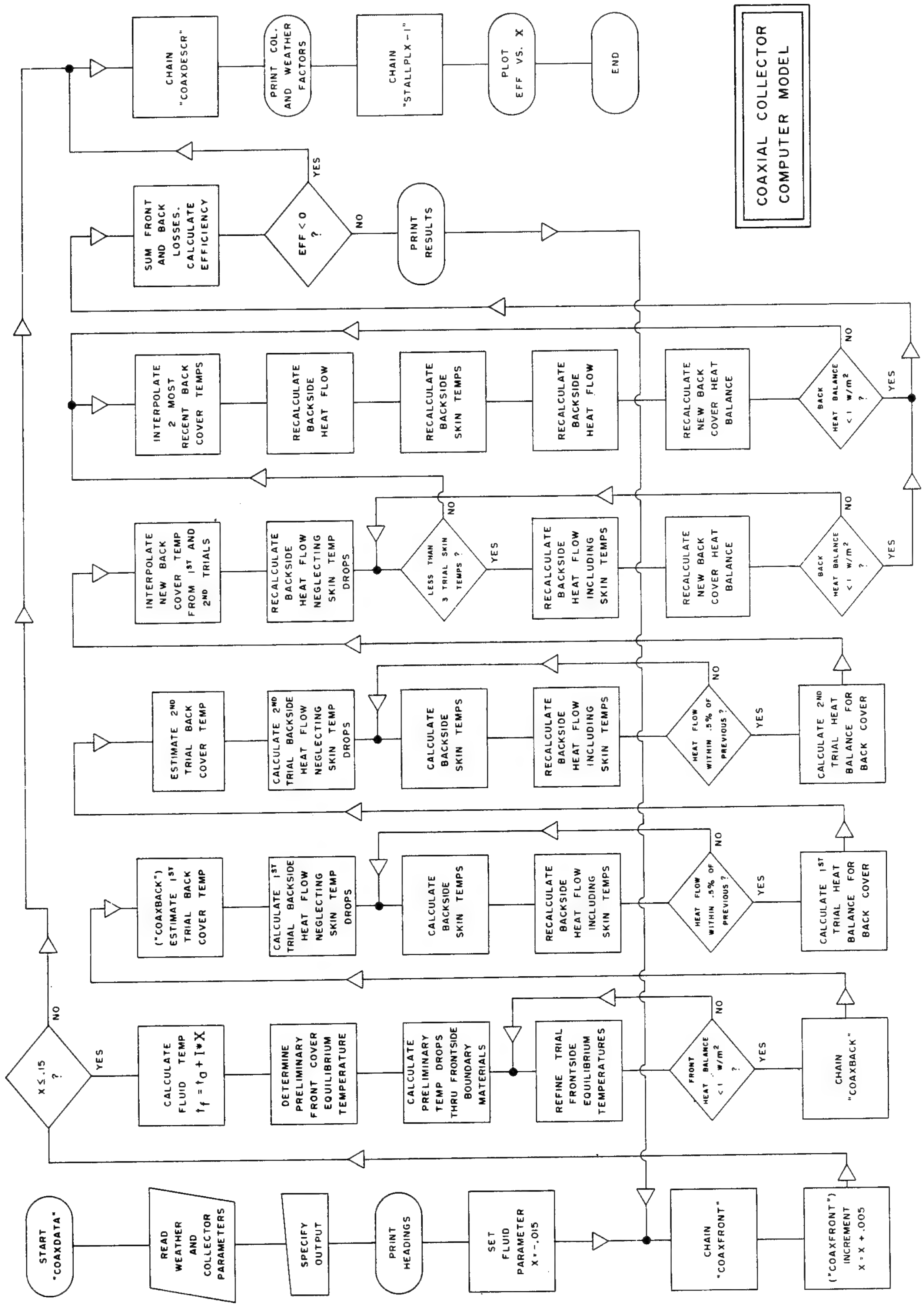
COMPUTER MODEL

EXHIBIT A

COAXIAL COLLECTOR

COMPUTER MODEL




COAXIAL COLLECTOR COMPUTER MODEL
START "COAXDATA"
READ WEATHER AND COLLECTOR PARAMETERS
SPECIFY OUTPUT
PRINT HEADINGS
SET FLUID PARAMETER X = -.015
CHAIN "COAXFRONT"
("COAXFRONT") INCREMENT X = X + .005
X ≤ .15 ?
YES
NO
CALCULATE FLUID TEMP $t_f = t_a + I*X$
DETERMINE PRELIMINARY FRONT COVER EQUILIBRIUM TEMPERATURE
CALCULATE PRELIMINARY TEMP DROPS THRU FRONTSIDE BOUNDARY MATERIALS
REFINE TRIAL FRONTSIDE EQUILIBRIUM TEMPERATURES
FRONT HEAT BALANCE < 1 w/m² ?
CHAIN "COAXBACK"
("COAXBACK") ESTIMATE 1ST TRIAL BACK COVER TEMP
CALCULATE 1ST TRIAL BACKSIDE HEAT FLOW NEGLECTING SKIN TEMP DROPS
CALCULATE BACKSIDE SKIN TEMPS
RECALCULATE BACKSIDE HEAT FLOW INCLUDING SKIN TEMPS
HEAT FLOW WITHIN .5% OF PREVIOUS ?
CALCULATE 1ST TRIAL HEAT BALANCE FOR BACK COVER
ESTIMATE 2ND TRIAL BACK COVER TEMP
CALCULATE 2ND TRIAL BACKSIDE HEAT FLOW NEGLECTING SKIN TEMP DROPS
CALCULATE BACKSIDE SKIN TEMPS
RECALCULATE BACKSIDE HEAT FLOW INCLUDING SKIN TEMPS
HEAT FLOW WITHIN .5% OF PREVIOUS ?
CALCULATE 2ND TRIAL HEAT BALANCE FOR BACK COVER
INTERPOLATE NEW BACK COVER TEMP FROM 1ST AND 2ND TRIALS
RECALCULATE BACKSIDE HEAT FLOW NEGLECTING SKIN TEMP DROPS
LESS THAN 3 TRIAL SKIN TEMPS ?
RECALCULATE BACKSIDE HEAT FLOW INCLUDING SKIN TEMPS
RECALCULATE NEW BACK COVER HEAT BALANCE
BACK HEAT BALANCE < 1 w/m² ?
INTERPOLATE 2 MOST RECENT BACK COVER TEMPS
RECALCULATE BACKSIDE HEAT FLOW
RECALCULATE BACKSIDE SKIN TEMPS
RECALCULATE BACKSIDE HEAT FLOW
RECALCULATE NEW BACK COVER HEAT BALANCE
BACK HEAT BALANCE < 1 w/m² ?
SUM FRONT AND BACK LOSSES. CALCULATE EFFICIENCY
EFF < 0 ?
PRINT RESULTS
CHAIN "COAXDESCR"
PRINT COL. AND WEATHER FACTORS
CHAIN "STALLPLX-1"
PLOT EFF VS. X
END

PRINCIPAL EQUATIONS USED IN COAXIAL COLLECTOR PROGRAM

$$Eff = (I-Qlosses)/I \tag{1}$$

$$Qlosses = QLfront + QLback \tag{2}$$

$$QLfront = Qconvf + Qradf + Qrefl \tag{3}$$

$$Qconvf + Qradf = Qairf + Qracf + Qribf + R9 \tag{4}$$

$$Qconvf = [3.14+4.19Vwind][tcovf-tamb] \tag{5}$$

$$Qradf = sigma \times [EcovfTcovf^4 - EskyTamb^4] \tag{6}$$

$$Qrefl = I \times [Rcov+(1-Aabs)(1-Acov-Rcov)^2] \tag{7}$$

$$Qairf = hairf(tabsf-tcovf) \tag{8}$$

$$Qracf = sigma \times R2 \times (Tabs^4-Tcovf^4)/(1/Eabs + 1/Ecov -1) \tag{9}$$

$$Qribf = [(K6/L8)(2L6/(D1+2L6)] \times (Tabsf-Tcovf) \tag{10}$$

$$R9 = I \times A6 \times [1+(1-A6-R6)(1-A7)] \tag{11}$$

$$QLback = (Tfluid-Tback)/(Zfluid+Zabsb+Zacb+Zcovb) \tag{12}$$

$$Qradb+Qconvb = (Tfluid-Tback)/(Zfluid+Zabsb+Zacb+Zcovb) \tag{13}$$

$$Zfluid = .00264 \text{ Deg C}/(W/m2) \tag{14}$$

$$Zabsb = L7/K7 \tag{15}$$

$$Zacb = 1/(hairb + R2 \times hrb + hribb) \tag{16}$$

$$Zcovb = L5/K5 \tag{17}$$

$$Qradb = sigma \times [Ecovb \times Tcovb^4-Esky \times Tamb^4] \tag{18}$$

$$Qconvb = [3.14+4.19 \times Vwind][tcovb-tamb] \tag{19}$$

$$hair = Nu \times Kair/Lair \tag{20}$$

$$Kair \approx .0284 + 7.1 \times 10^{-5} (tair-60) \tag{21}$$

$$R2 = 0.6 \tag{22}$$

$$hrb = 4 \times sigma \times Tair^3/(1/E5+1/E7-1) \tag{23}$$

$$hribb = [(K5/L2)(2L5)/(D1+2L5)] \tag{24}$$

$Nu_1 = .321 Gr^{.165}$ (Convection up, Gr<=5000, Col @45 deg) (25)

$Nu_2 = .093 Gr^{.31}$ (Convection up, Gr>5000, Col @ 45 deg) (26)

$Nu_3 = .151 Gr^{.281}$ (Convection up, horizontal Collector) (27)

$Nu_4 = Log^{-1}[.0119(Log\ Gr)^3 - .154(Log\ Gr)^2 + .708 Log Gr - 1.123]$
(Convection down, horizontal collector) (28)

$Nu_5 = .318 Gr^{.13}$ (Convect. down, Gr<=25000, Col @45 deg) (29)

$Nu_6 = .0452 Gr^{.323}$ (Convect. down, Gr>25000, Col @45 Deg) (30)

$Gr = g(\Delta Tair) Lair^3 / \nu^2\ Tair$ (31)

$\nu = 1.3\times10^{-5} + 9.61\times10^{-8}\ x tair$ (32)

(SEE SYMBOL DEFINITIONS, FOLLOWING PAGE.)

SYMBOLS USED IN COAXIAL COLLECTOR FORMULAS

Aabs=A7	Absorptivity of absorber (frontside)
Acov=A6	Absorptivity of cover (frontside)
D1	Outside Diameter of absorber
ΔTair	Temperature difference, convection boundaries, Degrees Kelvin
Eabs=E7	Emissivity of absorber
Ecov=Ecovf	Emissivity of front cover
Ecovb=E5	Emissivity of back cover
Eff	Collector efficiency
g	Acceleration of gravity
Gr	Grashof Number
hair	Convection + Conduction heat transfer coefficient for air (general form)
hairb	Convection + Conduction heat transfer coefficient for backside air
hairf	Convection + Conduction heat transfer coefficient for frontside air
hrb	Radiation heat transfer coefficient, backside air
hribb	Heat transfer coefficient for backside ribs
I	Global insolation
Kair	Thermal conductivity of air
K5	Thermal conductivity of back cover
K7	Thermal conductivity of absorber
Lair	Distance between convection boundaries (general form)
L2	Distance between absorber and inside back cover
L5	Thickness of back cover

L6	Thickness of front cover
L7	Thickness of absorber tube
L8	Distance between absorber and inside front cover
ν	Kinematic viscosity of air
Nu	Nusselt Number
Qairf	Heat transferred between absorber and front cover by convection and conduction
Qconvb	Heat convected away from back cover by ambient air
Qconvf	Heat convected away from front cover by ambient air
QLback	Total heat losses from back of collector
QLfront	Total heat losses from front of collector
Qlosses	Total heat losses from collector
Qracf	Heat transferred by radiation between absorber and front cover
Qradb	Heat radiated to ambient by back cover
Qradf	Radiant heat exchange between front cover and sky
Qrefl	Heat reflection losses from front of collector
Qribf	Heat conducted from absorber to front cover by ribs
Rcov=R6	Reflectivity of front cover
R2	Multiplier accounting for radiant view factor, absorber to covers
R9	Visible radiation absorbed by cover
sigma	Stefan-Boltzman constant
tabsf	Temperature of frontside of absorber (Deg c)
Tabsf=Tabs	Temperature of frontside of absorber (Deg K)

tair	Average temperature of confined air (Deg C)
Tair	Average temperature of confined air (Deg K)
ΔTair	Temperature difference, convection boundaries, (Deg K)
tamb	Ambient temperature, degrees C
Tamb	Ambient temperature, degrees K *
Tback	Back cover outside surface temperature, Deg K
tcovb	Back cover outside surface temperature, Deg C
Tcovb=Tback	
tcovf	Inside surface temperature, front cover, Deg C
Tcovf	Outside surface temperature, front cover, Deg K
Tfluid	Avg temperature of fluid in collector, Deg K *
Vwind	Wind speed over collector covers
Zabsb	Thermal resistance of absorber tube
Zacb	Net thermal resistance between absorber and inside back cover
Zcovb	Thermal resistance of back cover
Zfluid	Thermal resistance of laminar water film wetting absorber surface

*Note however, that for user convenience, these temperatures are expressed in Deg C in computer print-out headings during execution of coaxial collector program.

SPECIAL SYMBOLS USED IN COMPUTER PRINT-OUT HEADINGS

Tco	Outside surface temperature of front cover, Deg C
Tci	Inside surface temperature of front cover, Deg C
Tabs1	Outer front surface temperature of absorber, Deg C
Tabs2	Inner front surface temperature of absorber, Deg C
Tabs3	Inner back surface temperature of absorber, Deg C
Tabs4	Outer back surface temperature of absorber, Deg C
Tbin	Inner surface temperature of back cover, Deg C
Tbout	Outer surface temperature of back cover, Deg C
HEAT BALANCE	(Heat In - Heat Out) for front and back covers. (Would converge to 0 for perfect balance)
Qfront	Total heat losses from front of collector. (Positive values represent gains.)
Qribf	That portion of total frontal losses resulting from front rib conduction
Qback	Total heat losses from back of collector.
Qribb	That portion of total back losses resulting from back rib conduction
Grf	Grashof Number for front air space
Nuf	Nusselt Number for front air space
Grb	Grashof Number for back air space
Nub	Nusselt Number for back air space

CASE 1

19.1 mm Height

Air Backing

0.0 Wind Velocity

RUN
COAXDATA

PRINT GRASHOF AND NUSSELT NUMBERS, OR LOSSES (N/L)? L

NOTES: I=GLOBAL INSOLATION, [W/m2].
X=FLUID PARAMETER, (Tfluid-Tamb)/I, [DegC/(W/m2)].
EFF=(I-Qlosses)/I.

Tfluid DegC	Tamb DegC	I W/m2	X	EFF	Tco DegC	Tci DegC	Tabs1 DegC	Tabs2 DegC	Tabs3 DegC	Tabs4 DegC	Tbin DegC	Tbout DegC	HEAT BALANCE Front W/m2	Back W/m2	FRONT AND BACK LOSSES Qfront W/m2	Qribf W/m2	Qback W/m2	Qribb W/m2
12.0	21.1	910	-.010	+0.934	23.5	23.4	17.91	14.32	12.1	12.2	15.9	15.9	-0.21	-0.3	-92	11	31	7
16.5	21.1	910	-.005	+0.893	25.7	25.7	22.34	18.82	16.6	16.6	18.2	18.2	-0.20	-0.3	-110	6	13	3
21.1	21.1	910	0.000	+0.852	27.9	27.9	26.76	23.32	21.1	21.1	20.5	20.5	-0.19	-0.3	-130	2	-5	-1
25.6	21.1	910	0.005	+0.810	30.2	30.2	31.18	27.82	25.6	25.5	22.8	22.8	-0.19	-0.3	-149	-2	-24	-5
30.2	21.1	910	0.010	+0.767	32.5	32.5	35.59	32.32	30.1	29.9	25.1	25.1	-0.18	-0.3	-169	-6	-43	-9
34.7	21.1	910	0.015	+0.723	34.7	34.8	40.01	36.81	34.6	34.3	27.5	27.4	-0.17	-0.3	-189	-10	-63	-13
39.3	21.1	910	0.020	+0.678	37.0	37.1	44.42	41.31	39.1	38.7	29.8	29.7	-0.16	-0.2	-210	-14	-83	-17
43.8	21.1	910	0.025	+0.632	39.4	39.5	48.82	45.80	43.6	43.2	32.2	32.1	-0.15	-0.2	-231	-18	-104	-21
48.4	21.1	910	0.030	+0.585	41.7	41.8	53.23	50.30	48.1	47.6	34.6	34.5	-0.14	-0.1	-253	-22	-125	-25
52.9	21.1	910	0.035	+0.536	44.1	44.2	57.63	54.79	52.6	52.0	37.0	36.8	-0.13	-0.1	-275	-26	-147	-29
57.5	21.1	910	0.040	+0.487	46.4	46.6	62.03	59.28	57.1	56.4	39.4	39.2	-0.12	-0.0	-298	-30	-169	-33
62.1	21.1	910	0.045	+0.437	48.8	49.0	66.42	63.77	61.5	60.8	41.8	41.7	-0.10	+0.0	-321	-33	-191	-36
66.6	21.1	910	0.050	+0.386	51.2	51.4	70.81	68.25	66.0	65.2	44.3	44.1	-0.09	+0.1	-345	-37	-214	-40
71.2	21.1	910	0.055	+0.334	53.6	53.9	75.20	72.74	70.5	69.5	46.8	46.5	-0.08	+0.2	-369	-41	-237	-44
75.7	21.1	910	0.060	+0.280	56.0	56.3	79.58	77.23	75.0	73.9	49.2	49.0	-0.07	+0.3	-394	-45	-261	-47
80.3	21.1	910	0.065	+0.226	58.5	58.8	83.96	81.71	79.5	78.3	51.7	51.4	-0.06	+0.4	-419	-48	-286	-51
84.8	21.1	910	0.070	+0.170	60.9	61.3	88.34	86.19	84.0	82.7	54.2	53.9	-0.05	+0.5	-445	-52	-311	-55
89.4	21.1	910	0.075	+0.113	63.4	63.7	92.71	90.67	88.5	87.1	56.8	56.4	-0.04	+0.6	-471	-56	-336	-58
93.9	21.1	910	0.080	+0.055	65.9	66.3	97.08	95.15	92.9	91.5	59.3	58.9	-0.02	+0.7	-498	-59	-363	-62

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RUN
COAXDATA

PRINT GRASHOF AND NUSSELT NUMBERS, OR LOSSES (N/L)? N

NOTES:  I=GLOBAL INSOLATION, [W/m2].
        X=FLUID PARAMETER, (Tfluid-Tamb)/I, [DegC/(W/m2)].
        EFF=(I-Qlosses)/I.
```

Tfluid DegC	Tamb DegC	I W/m2	X	EFF	Tco DegC	Tci DegC	Tabs1 DegC	Tabs2 DegC	Tabs3 DegC	Tabs4 DegC	Tbin DegC	Tbout DegC	HEAT BALANCE Front W/m2	HEAT BALANCE Back W/m2	GRASHOF AND NUSSELT NUMBERS Grf	Nuf	Grb	Nub
12.0	21.1	910	-.010	+0.934	23.5	23.4	17.91	14.32	12.1	12.2	15.9	15.9	-0.21	-0.3	209	1.0	157	1.0
16.5	21.1	910	-.005	+0.893	25.7	25.7	22.34	18.82	16.6	16.6	18.2	18.2	-0.20	-0.3	120	1.0	62	1.0
21.1	21.1	910	0.000	+0.852	27.9	27.9	26.76	23.32	21.1	21.1	20.5	20.5	-0.19	-0.3	40	1.0	22	1.0
25.6	21.1	910	0.005	+0.810	30.2	30.2	31.18	27.82	25.6	25.5	22.8	22.8	-0.19	-0.3	32	1.0	97	1.0
30.2	21.1	910	0.010	+0.767	32.5	32.5	35.59	32.32	30.1	29.9	25.1	25.1	-0.18	-0.3	96	1.0	163	1.0
34.7	21.1	910	0.015	+0.723	34.7	34.8	40.01	36.81	34.6	34.3	27.5	27.4	-0.17	-0.3	153	1.0	222	1.0
39.3	21.1	910	0.020	+0.678	37.0	37.1	44.42	41.31	39.1	38.7	29.8	29.7	-0.16	-0.2	204	1.0	274	1.0
43.8	21.1	910	0.025	+0.632	39.4	39.5	48.82	45.80	43.6	43.2	32.2	32.1	-0.15	-0.2	249	1.0	320	1.0
48.4	21.1	910	0.030	+0.585	41.7	41.8	53.23	50.30	48.1	47.6	34.6	34.5	-0.14	-0.1	289	1.0	361	1.0
52.9	21.1	910	0.035	+0.536	44.1	44.2	57.63	54.79	52.6	52.0	37.0	36.8	-0.13	-0.1	325	1.0	397	1.0
57.5	21.1	910	0.040	+0.487	46.4	46.6	62.03	59.28	57.1	56.4	39.4	39.2	-0.12	-0.0	356	1.0	428	1.0
62.1	21.1	910	0.045	+0.437	48.8	49.0	66.42	63.77	61.5	60.8	41.8	41.7	-0.10	+0.0	384	1.0	455	1.0
66.6	21.1	910	0.050	+0.386	51.2	51.4	70.81	68.25	66.0	65.2	44.3	44.1	-0.09	+0.1	409	1.0	479	1.0
71.2	21.1	910	0.055	+0.334	53.6	53.9	75.20	72.74	70.5	69.5	46.8	46.5	-0.08	+0.2	430	1.0	500	1.0
75.7	21.1	910	0.060	+0.280	56.0	56.3	79.58	77.23	75.0	73.9	49.2	49.0	-0.07	+0.3	449	1.0	517	1.0
80.3	21.1	910	0.065	+0.226	58.5	58.8	83.96	81.71	79.5	78.3	51.7	51.4	-0.06	+0.4	465	1.0	533	1.0
84.8	21.1	910	0.070	+0.170	60.9	61.3	88.34	86.19	84.0	82.7	54.2	53.9	-0.05	+0.5	479	1.0	545	1.0
89.4	21.1	910	0.075	+0.113	63.4	63.7	92.71	90.67	88.5	87.1	56.8	56.4	-0.04	+0.6	491	1.0	556	1.0
93.9	21.1	910	0.080	+0.055	65.9	66.3	97.08	95.15	92.9	91.5	59.3	58.9	-0.02	+0.7	502	1.0	565	1.0

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COLLECTOR AND ENVIRONMENTAL FACTORS:

INSOLATION NORMAL TO COLLECTOR (W/SQ M)= 910
AMBIENT AIR TEMPERATURE (DEG C)= 21.1
COLLECTOR TILT ANGLE (DEG)= 45
EFFECTIVE SKY EMISSIVITY (f(Dew Pt))= .855
WIND SPEED (M/SEC)= 0

EMISSIVITY OF COVER= .88
TRANSMITTANCE OF COVER= .92
ABSORPTANCE OF COVER= .08
REFLECTANCE OF COVER= 0
CONDUCTIVITY OF COVER (W/M/DEG K)= .203
THICKNESS OF COVER (MM)= .203

RIB HEIGHT (DISTANCE BETWEEN 'COVER' AND ABSORBER), (cm) = .635
RADIANT TRANSFER VIEW FACTOR (ABSORBER TO COVER)= .6

ABSORBER TUBE O.D. (mm)= 6.35
ABSORBER SKIN THICKNESS (MM)= .718
CONDUCTIVITY OF ABSORBER SKIN (W/M/DEG K)= .1759
ABSORBER EMISSIVITY= .92
ABSORBER ABSORPTIVITY= .92

THICKNESS OF BACKING #1 (AIR WITH RIBS), (cm) = .635

THICKNESS OF BACKING #2 (PLASTIC), (mm) = .203
CONDUCTIVITY OF BACKING #2 (W/M/DEG K)= .203
EMISSIVITY OF BACKING #2 = .88
ABSORPTIVITY OF BACKING #2= .88
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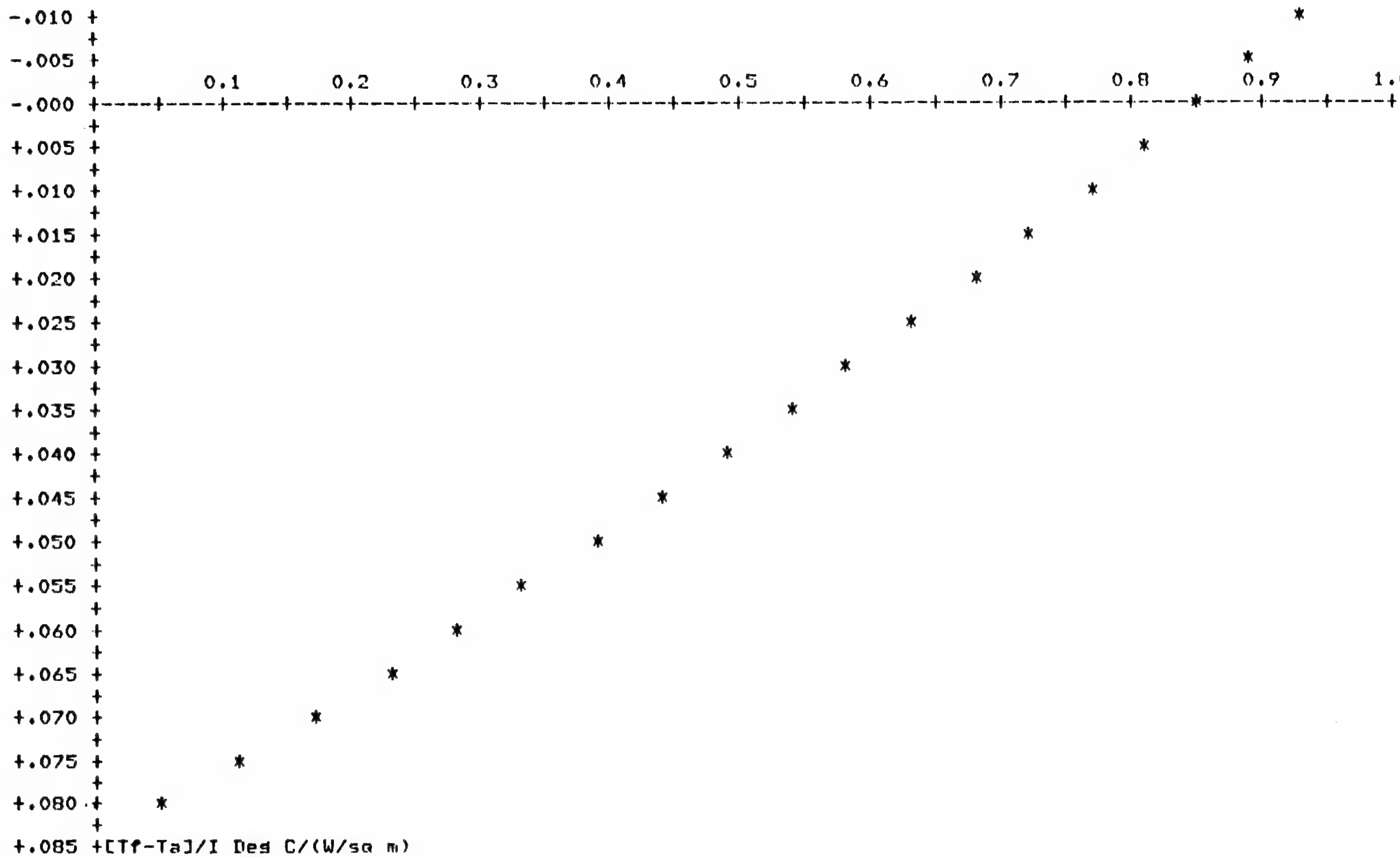
COLLECTOR EFFICIENCY



EFFICIENCY=0 AT Xo= .084 (Deg C)/(W/sq m)
Tstall = Tamb+1000*Xo =Tamb+ 84.2 DEGREES C.

CASE 2

22.2 mm Height

Air Backing

0.0 Wind Velocity

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RUN
COAXDATA

PRINT GRASHOF AND NUSSELT NUMBERS, OR LOSSES (N/L)? L

NOTES:  I=GLOBAL INSOLATION, [W/m2].
        X=FLUID PARAMETER, (Tfluid-Tamb)/I, [DegC/(W/m2)].
        EFF=(I-Qlosses)/I.
```

Tfluid DegC	Tamb DegC	I W/m2	X	EFF	Tco DegC	Tci DegC	Tabs1 DegC	Tabs2 DegC	Tabs3 DegC	Tabs4 DegC	Tbin DegC	Tbout DegC	HEAT BALANCE Front W/m2	HEAT BALANCE Back W/m2	FRONT AND BACK LOSSES Qfront W/m2	Qribf W/m2	Qback W/m2	Qribb W/m2
12.0	21.1	910	-.010	+0.928	23.8	23.8	17.89	14.31	12.1	12.2	16.2	16.2	-0.15	-0.2	-95	9	29	6
16.5	21.1	910	-.005	+0.890	25.9	25.9	22.32	18.82	16.6	16.6	18.3	18.3	-0.15	-0.2	-112	5	12	3
21.1	21.1	910	0.000	+0.852	28.0	28.0	26.75	23.32	21.1	21.1	20.4	20.4	-0.15	-0.3	-130	2	-5	-1
25.6	21.1	910	0.005	+0.812	30.1	30.1	31.18	27.82	25.6	25.5	22.6	22.6	-0.14	-0.4	-148	-2	-22	-4
30.2	21.1	910	0.010	+0.772	32.2	32.3	35.61	32.32	30.1	29.9	24.8	24.7	-0.14	-0.5	-167	-5	-40	-8
34.7	21.1	910	0.015	+0.731	34.4	34.4	40.03	36.82	34.6	34.4	27.0	26.9	-0.13	-0.5	-186	-9	-59	-11
39.3	21.1	910	0.020	+0.689	36.5	36.6	44.45	41.32	39.1	38.8	29.2	29.1	-0.13	-0.6	-206	-12	-78	-15
43.8	21.1	910	0.025	+0.646	38.7	38.8	48.86	45.82	43.6	43.2	31.4	31.3	-0.12	-0.6	-225	-15	-97	-18
48.4	21.1	910	0.030	+0.602	40.9	41.0	53.28	50.32	48.1	47.6	33.7	33.6	-0.11	-0.6	-246	-19	-117	-21
52.9	21.1	910	0.035	+0.557	43.1	43.3	57.69	54.81	52.6	52.0	36.0	35.8	-0.10	-0.7	-267	-22	-137	-25
57.5	21.1	910	0.040	+0.511	45.4	45.5	62.09	59.30	57.1	56.4	38.3	38.1	-0.09	-0.7	-288	-25	-157	-28
62.1	21.1	910	0.045	+0.463	47.6	47.8	66.50	63.80	61.6	60.8	40.6	40.4	-0.08	-0.7	-310	-29	-179	-31
66.6	21.1	910	0.050	+0.415	49.9	50.1	70.90	68.29	66.1	65.3	42.9	42.7	-0.06	-0.6	-332	-32	-200	-34
71.2	21.1	910	0.055	+0.366	52.2	52.4	75.30	72.78	70.6	69.7	45.3	45.0	+0.06	-0.6	-355	-35	-222	-37
75.7	21.1	910	0.060	+0.315	54.5	54.8	79.69	77.27	75.1	74.0	47.6	47.4	+0.16	-0.6	-378	-38	-245	-41
80.3	21.1	910	0.065	+0.264	56.9	57.1	84.08	81.75	79.5	78.4	50.0	49.7	-0.01	-0.5	-402	-41	-268	-44
84.8	21.1	910	0.070	+0.211	59.2	59.5	88.46	86.24	84.0	82.8	52.4	52.1	-0.01	-0.5	-427	-44	-292	-47
89.4	21.1	910	0.075	+0.156	61.6	61.9	92.84	90.72	88.5	87.2	54.8	54.5	-0.00	-0.4	-452	-47	-316	-50
93.9	21.1	910	0.080	+0.101	64.0	64.4	97.22	95.20	93.0	91.6	57.3	56.9	+0.01	-0.3	-478	-50	-341	-53
98.4	21.1	910	0.085	+0.044	66.5	66.8	101.59	99.68	97.5	96.0	59.7	59.3	+0.01	-0.3	-504	-53	-366	-56

RUN
COAXDATA

PRINT GRASHOF AND NUSSELT NUMBERS, OR LOSSES (N/L)? N

NOTES: I=GLOBAL INSOLATION, [W/m2].
X=FLUID PARAMETER, (Tfluid-Tamb)/I, [DegC/(W/m2)].
EFF=(I-Qlosses)/I.

Tfluid DegC	Tamb DegC	I W/m2	X	EFF	Tco DegC	Tci DegC	Tabs1 DegC	Tabs2 DegC	Tabs3 DegC	Tabs4 DegC	Tbin DegC	Tbout DegC	HEAT BALANCE Front W/m2	HEAT BALANCE Back W/m2	GRASHOF AND NUSSELT NUMBERS Grf	Nuf	Grb	Nub
12.0	21.1	910	-.010	+0.928	23.8	23.8	17.89	14.31	12.1	12.2	16.2	16.2	-0.15	-0.2	439	1.0	327	1.0
16.5	21.1	910	-.005	+0.890	25.9	25.9	22.32	18.82	16.6	16.6	18.3	18.3	-0.15	-0.2	251	1.0	130	1.0
21.1	21.1	910	0.000	+0.852	28.0	28.0	26.75	23.32	21.1	21.1	20.4	20.4	-0.15	-0.3	83	1.0	47	1.0
25.6	21.1	910	0.005	+0.812	30.1	30.1	31.18	27.82	25.6	25.5	22.6	22.6	-0.14	-0.4	67	1.0	205	1.0
30.2	21.1	910	0.010	+0.772	32.2	32.3	35.61	32.32	30.1	29.9	24.8	24.7	-0.14	-0.5	202	1.0	344	1.0
34.7	21.1	910	0.015	+0.731	34.4	34.4	40.03	36.82	34.6	34.4	27.0	26.9	-0.13	-0.5	322	1.0	469	1.0
39.3	21.1	910	0.020	+0.689	36.5	36.6	44.45	41.32	39.1	38.8	29.2	29.1	-0.13	-0.6	429	1.0	579	1.0
43.8	21.1	910	0.025	+0.646	38.7	38.8	48.86	45.82	43.6	43.2	31.4	31.3	-0.12	-0.6	525	1.0	676	1.0
48.4	21.1	910	0.030	+0.602	40.9	41.0	53.28	50.32	48.1	47.6	33.7	33.6	-0.11	-0.6	610	1.0	762	1.0
52.9	21.1	910	0.035	+0.557	43.1	43.3	57.69	54.81	52.6	52.0	36.0	35.8	-0.10	-0.7	685	1.0	837	1.0
57.5	21.1	910	0.040	+0.511	45.4	45.5	62.09	59.30	57.1	56.4	38.3	38.1	-0.07	-0.7	752	1.0	903	1.0
62.1	21.1	910	0.045	+0.463	47.6	47.8	66.50	63.80	61.6	60.8	40.6	40.4	-0.08	-0.7	811	1.0	961	1.0
66.6	21.1	910	0.050	+0.415	49.9	50.1	70.90	68.29	66.1	65.3	42.9	42.7	-0.06	-0.6	863	1.0	1012	1.0
71.2	21.1	910	0.055	+0.366	52.2	52.4	75.30	72.78	70.6	69.7	45.3	45.0	+0.06	-0.6	909	1.0	1056	1.0
75.7	21.1	910	0.060	+0.315	54.5	54.8	79.69	77.27	75.1	74.0	47.6	47.4	+0.16	-0.6	949	1.0	1093	1.0
80.3	21.1	910	0.065	+0.264	56.9	57.1	84.08	81.75	79.5	78.4	50.0	49.7	-0.01	-0.5	982	1.0	1125	1.0
84.8	21.1	910	0.070	+0.211	59.2	59.5	88.46	86.24	84.0	82.8	52.4	52.1	-0.01	-0.5	1011	1.0	1152	1.0
89.4	21.1	910	0.075	+0.156	61.6	61.9	92.84	90.72	88.5	87.2	54.8	54.5	-0.00	-0.4	1035	1.0	1175	1.0
93.9	21.1	910	0.080	+0.101	64.0	64.4	97.22	95.20	93.0	91.6	57.3	56.9	+0.01	-0.3	1056	1.0	1194	1.0
98.4	21.1	910	0.085	+0.044	66.5	66.8	101.59	99.68	97.5	96.0	59.7	59.3	+0.01	-0.3	1073	1.0	1209	1.0

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COLLECTOR AND ENVIRONMENTAL FACTORS:

INSOLATION NORMAL TO COLLECTOR (W/SQ M)= 910
AMBIENT AIR TEMPERATURE (DEG C)= 21.1
COLLECTOR TILT ANGLE (DEG)= 45
EFFECTIVE SKY EMISSIVITY (f(Dew Pt))= .855
WIND SPEED (M/SEC)= 0

EMISSIVITY OF COVER= .88
TRANSMITTANCE OF COVER= .92
ABSORPTANCE OF COVER= .08
REFLECTANCE OF COVER= 0
CONDUCTIVITY OF COVER (W/M/DEG K)= .203
THICKNESS OF COVER (MM)= .203

RIB HEIGHT (DISTANCE BETWEEN 'COVER' AND ABSORBER), (cm) = .794
RADIANT TRANSFER VIEW FACTOR (ABSORBER TO COVER)= .6

ABSORBER TUBE O.D. (mm)= 6.35
ABSORBER SKIN THICKNESS (MM)= .718
CONDUCTIVITY OF ABSORBER SKIN (W/M/DEG K)= .1759
ABSORBER EMISSIVITY= .92
ABSORBER ABSORPTIVITY= .92


THICKNESS OF BACKING #1 (AIR WITH RIBS), (cm) = .794


THICKNESS OF BACKING #2 (PLASTIC), (mm) = .203
CONDUCTIVITY OF BACKING #2 (W/M/DEG K)= .203
EMISSIVITY OF BACKING #2 = .88
ABSORPTIVITY OF BACKING #2= .88
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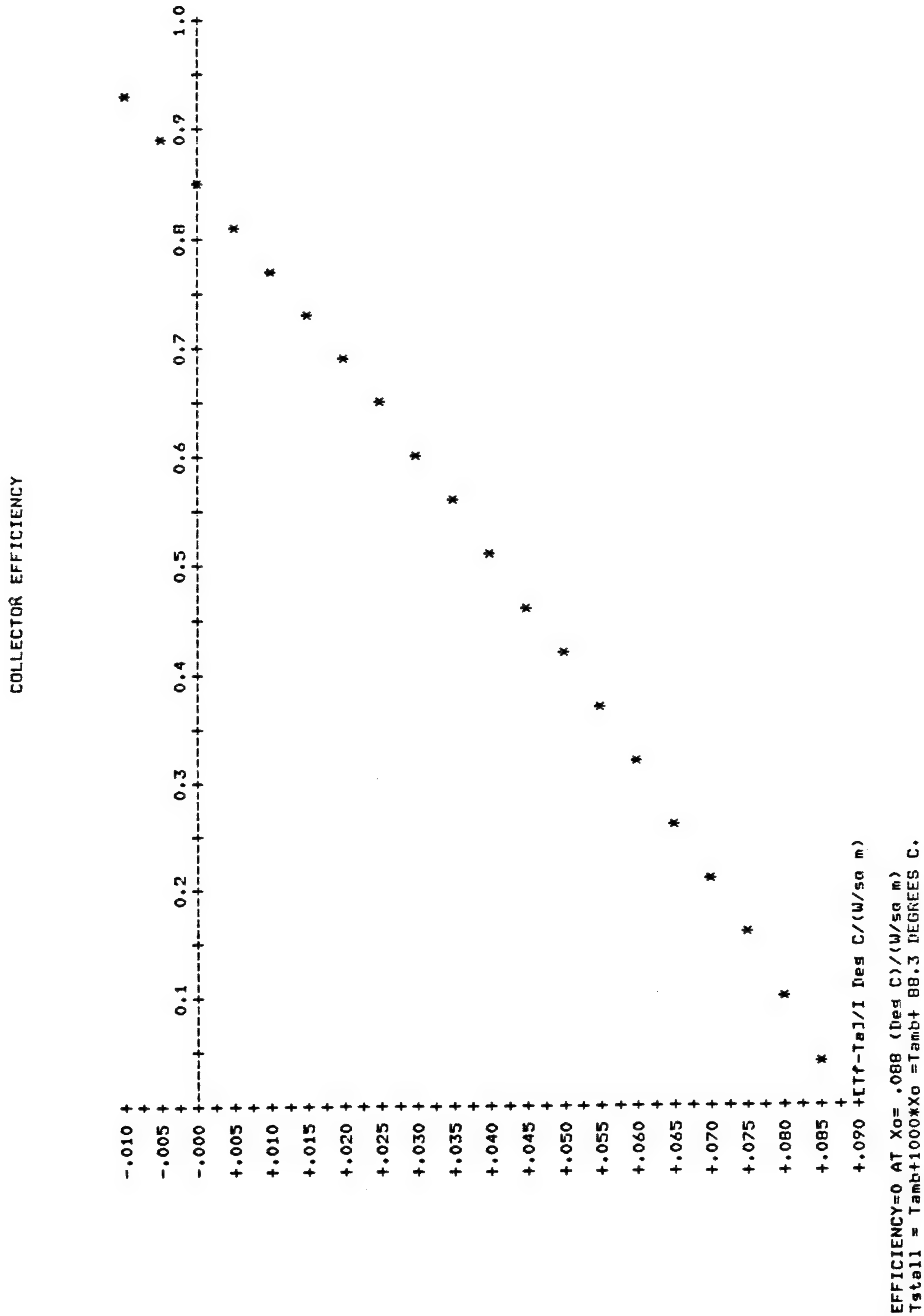
COLLECTOR EFFICIENCY
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
-.010
-.005
-.000
+.005
+.010
+.015
+.020
+.025
+.030
+.035
+.040
+.045
+.050
+.055
+.060
+.065
+.070
+.075
+.080
+.085
+.090 +[Tf-Ta]/I Deg C/(W/sq m)
EFFICIENCY=0 AT Xo= .088 (Deg C)/(W/sq m)
Tstall = Tamb+1000*Xo =Tamb+ 88.3 DEGREES C.

CASE 3

25.4 mm Height

Air Backing

0.0 Wind Velocity

PRINT GRASH AND NUSSELT NUMBERS, OR LOSSES (N/L)? L

NOTES: I=GLOBAL INSOLATION, [W/m2].
X=FLUID PARAMETER, (Tfluid-Tamb)/I, [DegC/(W/m2)].
EFF=(I-Qlosses)/I.

Tfluid DegC	Tamb DegC	I W/m2	X	EFF	Tco DegC	Tci DegC	Tabs1 DegC	Tabs2 DegC	Tabs3 DegC	Tabs4 DegC	Tbin DegC	Tbout DegC	HEAT BALANCE Front W/m2	Back W/m2	FRONT AND BACK LOSSES Qfront W/m2	Qribf W/m2	Qback W/m2	Qribb W/m2
12.0	21.1	910	-.010	+0.923	24.1	24.1	17.87	14.31	12.1	12.2	16.4	16.4	-0.12	-0.1	-90	8	27	5
16.5	21.1	910	-.005	+0.808	26.1	26.1	22.31	18.81	16.6	16.6	18.4	18.4	-0.12	-0.2	-114	5	12	2
21.1	21.1	910	0.000	+0.851	28.1	28.1	26.75	23.32	21.1	21.1	20.4	20.4	-0.12	-0.3	-131	2	-5	-1
25.6	21.1	910	0.005	+0.814	30.1	30.1	31.19	27.82	25.6	25.5	22.4	22.4	-0.12	-0.5	-148	-1	-21	-4
30.2	21.1	910	0.010	+0.776	32.1	32.1	35.62	32.33	30.1	29.9	24.5	24.5	-0.11	-0.6	-166	-5	-38	-7
34.7	21.1	910	0.015	+0.737	34.1	34.1	40.05	36.83	34.6	34.4	26.6	26.6	-0.11	-0.7	-184	-8	-56	-10
39.3	21.1	910	0.020	+0.697	36.1	36.2	44.47	41.33	39.1	38.8	28.7	28.7	+0.07	-0.8	-202	-11	-73	-13
43.8	21.1	910	0.025	+0.657	38.2	38.3	48.90	45.83	43.6	43.2	30.9	30.8	+0.07	-0.9	-221	-14	-92	-16
48.4	21.1	910	0.030	+0.614	40.4	40.5	53.31	50.33	48.1	47.7	33.0	32.8	-0.04	-0.0	-241	-16	-111	-19
52.9	21.1	910	0.035	+0.570	42.6	42.7	57.72	54.82	52.6	52.1	35.1	35.0	-0.04	+0.0	-261	-19	-130	-22
57.5	21.1	910	0.040	+0.526	44.8	44.9	62.13	59.32	57.1	56.5	37.3	37.2	-0.04	-0.0	-282	-22	-150	-25
62.1	21.1	910	0.045	+0.480	47.0	47.2	66.54	63.81	61.6	60.9	39.5	39.4	-0.04	+0.0	-303	-25	-170	-27
66.6	21.1	910	0.050	+0.433	49.2	49.4	70.94	68.31	66.1	65.3	41.8	41.6	-0.03	+0.0	-325	-28	-190	-30
71.2	21.1	910	0.055	+0.385	51.5	51.7	75.34	72.80	70.6	69.7	44.0	43.8	-0.03	+0.0	-348	-30	-211	-33
75.7	21.1	910	0.060	+0.337	53.8	54.0	79.74	77.29	75.1	74.1	46.3	46.1	-0.02	+0.0	-371	-33	-233	-36
80.3	21.1	910	0.065	+0.286	56.1	56.4	84.13	81.77	79.6	78.5	48.6	48.4	-0.02	+0.0	-394	-36	-255	-38
84.8	21.1	910	0.070	+0.235	58.4	58.7	88.52	86.26	84.1	82.9	50.9	50.7	-0.01	+0.0	-418	-38	-278	-41
89.4	21.1	910	0.075	+0.183	60.8	61.1	92.90	90.75	88.6	87.3	53.3	53.0	-0.01	+0.0	-443	-41	-301	-44
93.9	21.1	910	0.080	+0.129	63.1	63.5	97.29	95.23	93.0	91.7	55.7	55.3	+0.00	+0.0	-468	-43	-325	-46
98.4	21.1	910	0.085	+0.074	65.5	65.9	101.66	99.71	97.5	96.1	58.0	57.7	+0.01	+0.0	-493	-46	-349	-49
103.0	21.1	910	0.090	+0.018	67.9	68.3	106.04	104.19	102.0	100.5	60.4	60.1	+0.01	+0.0	-520	-48	-374	-51

RUN
COAXDATA

PRINT GRASHOF AND NUSSELT NUMBERS, OR LOSSES (N/L)? N

NOTES: I=GLOBAL INSOLATION, [W/m2].
X=FLUID PARAMETER, (Tfluid-Tamb)/I, [DegC/(W/m2)].
EFF=(I-Qlosses)/I.

Tfluid DegC	Tamb DegC	I W/m2	X	EFF	Tco DegC	Tci DegC	Tabs1 DegC	Tabs2 DegC	Tabs3 DegC	Tabs4 DegC	Tbin DegC	Tbout DegC	HEAT BALANCE Front W/m2	Back W/m2	GRASHOF AND NUSSELT NUMBERS Grf	Nuf	Grb	Nub
12.0	21.1	910	-.010	+0.923	24.1	24.1	17.87	14.31	12.1	12.2	16.4	16.4	-0.12	-0.1	797	1.0	599	1.0
16.5	21.1	910	-.005	+0.888	26.1	26.1	22.31	18.81	16.6	16.6	18.4	18.4	-0.12	-0.2	456	1.0	237	1.0
21.1	21.1	910	0.000	+0.851	28.1	28.1	26.75	23.32	21.1	21.1	20.4	20.4	-0.12	-0.3	151	1.0	86	1.0
25.6	21.1	910	0.005	+0.814	30.1	30.1	31.19	27.82	25.6	25.5	22.4	22.4	-0.12	-0.5	123	1.0	373	1.0
30.2	21.1	910	0.010	+0.776	32.1	32.1	35.62	32.33	30.1	29.9	24.5	24.5	-0.11	-0.6	368	1.0	628	1.0
34.7	21.1	910	0.015	+0.737	34.1	34.1	40.05	36.83	34.6	34.4	26.6	26.6	-0.11	-0.7	588	1.0	855	1.0
39.3	21.1	910	0.020	+0.697	36.1	36.2	44.47	41.33	39.1	38.8	28.7	28.7	+0.07	-0.8	784	1.0	1056	1.0
43.8	21.1	910	0.025	+0.657	38.2	38.3	48.90	45.83	43.6	43.2	30.9	30.8	+0.07	-0.9	959	1.0	1234	1.0
48.4	21.1	910	0.030	+0.614	40.4	40.5	53.31	50.33	40.1	47.7	33.0	32.8	-0.04	-0.0	1109	1.0	1397	1.0
52.9	21.1	910	0.035	+0.570	42.6	42.7	57.72	54.82	52.6	52.1	35.1	35.0	-0.04	+0.0	1242	1.0	1536	1.0
57.5	21.1	910	0.040	+0.526	44.8	44.9	62.13	59.32	57.1	56.5	37.3	37.2	-0.04	-0.0	1359	1.1	1657	1.0
62.1	21.1	910	0.045	+0.480	47.0	47.2	66.54	63.81	61.6	60.9	39.5	39.4	-0.04	+0.0	1462	1.1	1764	1.0
66.6	21.1	910	0.050	+0.433	49.2	49.4	70.94	68.31	66.1	65.3	41.8	41.6	-0.03	+0.0	1552	1.1	1856	1.0
71.2	21.1	910	0.055	+0.385	51.5	51.7	75.34	72.80	70.6	69.7	44.0	43.8	-0.03	+0.0	1631	1.1	1936	1.0
75.7	21.1	910	0.060	+0.337	53.8	54.0	79.74	77.29	75.1	74.1	46.3	46.1	-0.02	+0.0	1700	1.1	2005	1.0
80.3	21.1	910	0.065	+0.286	56.1	56.4	84.13	81.77	79.6	78.5	48.6	48.4	-0.02	+0.0	1759	1.1	2063	1.0
84.8	21.1	910	0.070	+0.235	58.4	58.7	88.52	86.26	84.1	82.9	50.9	50.7	-0.01	+0.0	1810	1.1	2113	1.0
89.4	21.1	910	0.075	+0.183	60.8	61.1	92.90	90.75	88.6	87.3	53.3	53.0	-0.01	+0.0	1854	1.1	2154	1.0
93.9	21.1	910	0.080	+0.129	63.1	63.5	97.29	95.23	93.0	91.7	55.7	55.3	+0.00	+0.0	1890	1.1	2188	1.0
98.4	21.1	910	0.085	+0.074	65.5	65.9	101.66	99.71	97.5	96.1	58.0	57.7	+0.01	+0.0	1921	1.1	2215	1.0
103.0	21.1	910	0.090	+0.018	67.9	68.3	106.04	104.19	102.0	100.5	60.4	60.1	+0.01	+0.0	1946	1.1	2236	1.0

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COLLECTOR AND ENVIRONMENTAL FACTORS:

INSOLATION NORMAL TO COLLECTOR (W/SQ M)= 910
AMBIENT AIR TEMPERATURE (DEG C)= 21.1
COLLECTOR TILT ANGLE (DEG)= 45
EFFECTIVE SKY EMISSIVITY (f(Dew Pt))= .855
WIND SPEED (M/SEC)= 0

EMISSIVITY OF COVER= .88
TRANSMITTANCE OF COVER= .92
ABSORPTANCE OF COVER= .08
REFLECTANCE OF COVER= 0
CONDUCTIVITY OF COVER (W/M/DEG K)= .203
THICKNESS OF COVER (MM)= .203

RIB HEIGHT (DISTANCE BETWEEN 'COVER' AND ABSORBER), (cm) = .953
RADIANT TRANSFER VIEW FACTOR (ABSORBER TO COVER)= .6

ABSORBER TUBE O.D. (mm)= 6.35
ABSORBER SKIN THICKNESS (MM)= .718
CONDUCTIVITY OF ABSORBER SKIN (W/M/DEG K)= .1759
ABSORBER EMISSIVITY= .92
ABSORBER ABSORPTIVITY= .92


THICKNESS OF BACKING #1 (AIR WITH RIBS), (cm) = .953


THICKNESS OF BACKING #2 (PLASTIC), (mm) = .203
CONDUCTIVITY OF BACKING #2 (W/M/DEG K)= .203
EMISSIVITY OF BACKING #2 = .88
ABSORPTIVITY OF BACKING #2= .88
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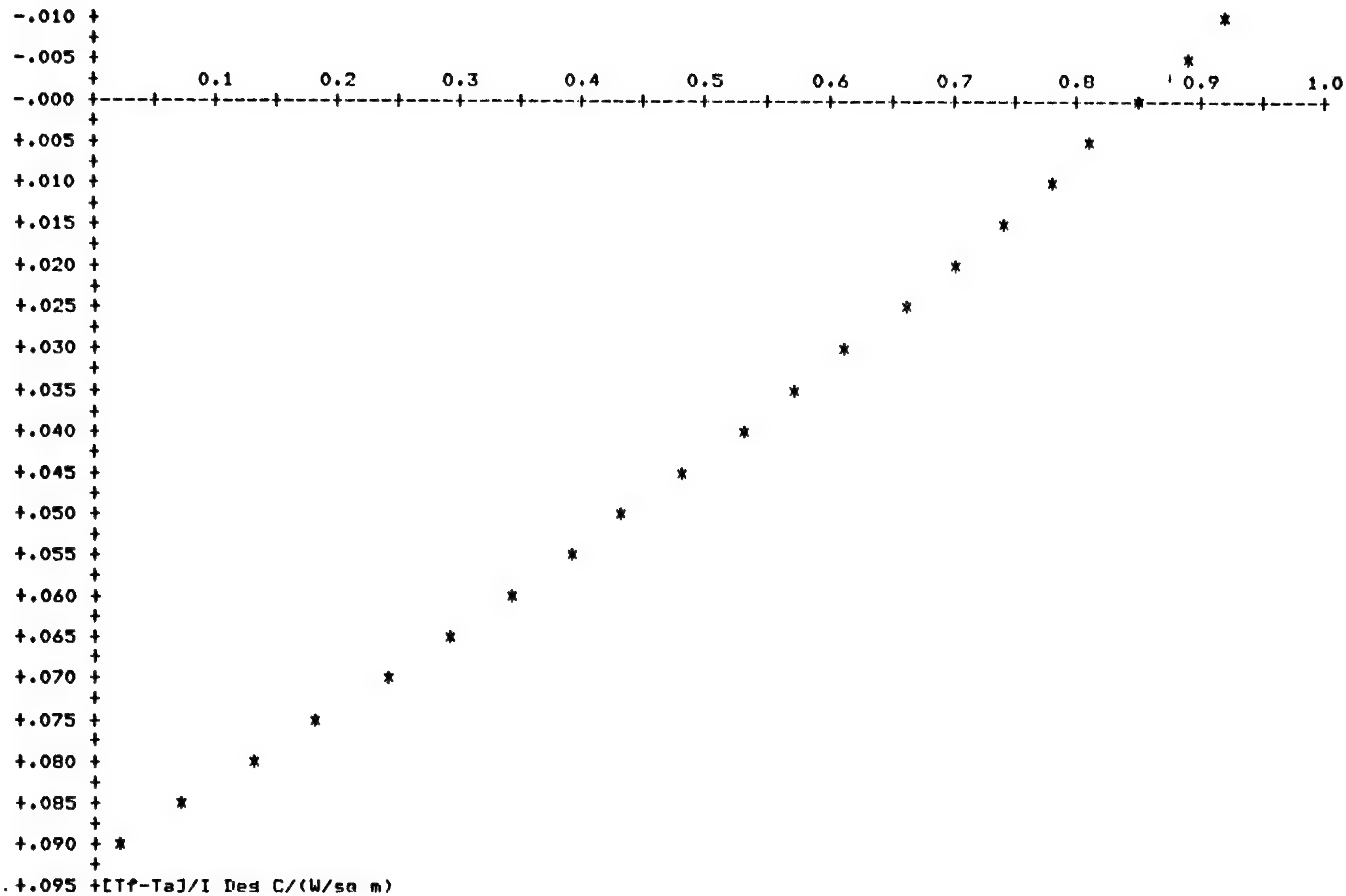

EFFICIENCY=0 AT Xo= .092 (Deg C)/(W/sq m)
Tstall = Tamb+1000*Xo =Tamb+ 92.0 DEGREES C.

CASE 4

19.1 mm Height

12.7 mm Polyurethane Backing

0.0 Wind Velocity

NOTES: I=GLOBAL INSOLATION, [W/m2].
X=FLUID PARAMETER, (Tfluid-Tamb)/I, [DegC/(W/m2)].
EFF=(I-Qlosses)/I.

Tfluid DegC	Tamb DegC	I W/m2	X	EFF	Tco DegC	Tci DegC	Tabs1 DegC	Tabs2 DegC	Tabs3 DegC	Tabs4 DegC	Tbin DegC	Tbout DegC	HEAT BALANCE Front W/m2	HEAT BALANCE Back W/m2	FRONT AND BACK LOSSES Qfront W/m2	Qribf W/m2	Qback W/m2	Qribb W/m2
12.0	21.1	910	-.010	+0.908	23.5	23.4	17.91	14.32	12.0	12.1	13.2	18.8	-0.21	+0.4	-92	11	8	0
16.5	21.1	910	-.005	+0.882	25.7	25.7	22.34	18.82	16.6	16.6	17.0	19.4	-0.20	+0.1	-110	6	3	0
21.1	21.1	910	0.000	+0.856	27.9	27.9	26.76	23.32	21.1	21.1	20.9	20.0	-0.19	-0.3	-130	2	-1	-0
25.6	21.1	910	0.005	+0.830	30.2	30.2	31.18	27.82	25.6	25.6	24.8	20.6	-0.19	-0.9	-149	-2	-6	-0
30.2	21.1	910	0.010	+0.803	32.5	32.5	35.59	32.32	30.2	30.1	28.7	21.1	-0.18	-0.0	-169	-6	-11	-0
34.7	21.1	910	0.015	+0.775	34.7	34.8	40.01	36.81	34.7	34.6	32.6	21.7	-0.17	+0.0	-189	-10	-15	-0
39.3	21.1	910	0.020	+0.747	37.0	37.1	44.42	41.31	39.2	39.2	36.5	22.3	-0.16	-0.0	-210	-14	-20	-0
43.8	21.1	910	0.025	+0.718	39.4	39.5	48.82	45.80	43.8	43.7	40.5	22.8	-0.15	-0.0	-231	-18	-25	-1
48.4	21.1	910	0.030	+0.689	41.7	41.8	53.23	50.30	48.3	48.2	44.5	23.4	-0.14	-0.0	-253	-22	-30	-1
52.9	21.1	910	0.035	+0.659	44.1	44.2	57.63	54.79	52.9	52.7	48.5	24.0	-0.13	-0.0	-275	-26	-35	-1
57.5	21.1	910	0.040	+0.629	46.4	46.6	62.03	59.28	57.4	57.2	52.6	24.6	-0.12	-0.0	-298	-30	-40	-1
62.1	21.1	910	0.045	+0.598	48.8	49.0	66.42	63.77	61.9	61.8	56.6	25.2	-0.10	-0.0	-321	-33	-45	-1
66.6	21.1	910	0.050	+0.567	51.2	51.4	70.81	68.25	66.5	66.3	60.7	25.8	-0.09	-0.0	-345	-37	-50	-1
71.2	21.1	910	0.055	+0.535	53.6	53.9	75.20	72.74	71.0	70.8	64.8	26.4	-0.08	-0.0	-369	-41	-55	-1
75.7	21.1	910	0.060	+0.502	56.0	56.3	79.58	77.23	75.5	75.3	68.9	26.9	-0.07	-0.0	-394	-45	-60	-1
80.3	21.1	910	0.065	+0.469	58.5	58.8	83.96	81.71	80.1	79.8	73.1	27.5	-0.06	-0.1	-419	-48	-65	-1
84.8	21.1	910	0.070	+0.435	60.9	61.3	88.34	86.19	84.6	84.3	77.2	28.1	-0.05	-0.1	-445	-52	-70	-1
89.4	21.1	910	0.075	+0.400	63.4	63.7	92.71	90.67	89.2	88.8	81.4	28.7	-0.04	-0.1	-471	-56	-75	-1
93.9	21.1	910	0.080	+0.365	65.9	66.3	97.08	95.15	93.7	93.4	85.6	29.3	-0.02	-0.1	-498	-59	-80	-1
98.4	21.1	910	0.085	+0.329	68.4	68.8	101.45	99.63	98.2	97.9	89.8	29.9	-0.01	-0.1	-525	-63	-85	-1
103.0	21.1	910	0.090	+0.293	70.9	71.3	105.81	104.10	102.8	102.4	94.0	30.5	-0.00	-0.2	-553	-66	-90	-1
107.5	21.1	910	0.095	+0.256	73.4	73.9	110.17	108.58	107.3	106.9	98.2	31.1	+0.01	-0.2	-582	-70	-95	-1
112.1	21.1	910	0.100	+0.218	76.0	76.4	114.52	113.05	111.8	111.4	102.5	31.7	+0.02	-0.2	-611	-73	-101	-2
116.6	21.1	910	0.105	+0.179	78.5	79.0	118.87	117.52	116.4	115.9	106.8	32.3	+0.03	-0.3	-641	-77	-106	-2
121.2	21.1	910	0.110	+0.140	81.1	81.6	123.22	121.99	120.9	120.5	111.0	32.9	+0.03	-0.3	-671	-80	-111	-2
125.7	21.1	910	0.115	+0.100	83.6	84.2	127.56	126.46	125.4	125.0	115.3	33.5	+0.04	-0.4	-703	-83	-116	-2
130.3	21.1	910	0.120	+0.059	86.2	86.8	131.89	130.93	130.0	129.5	119.6	34.1	+0.04	-0.5	-734	-87	-122	-2
134.8	21.1	910	0.125	+0.018	88.8	89.4	136.23	135.39	134.5	134.0	124.0	34.7	+0.04	-0.6	-767	-90	-127	-2

NOTES: I=GLOBAL INSOLATION, [W/m2].
X=FLUID PARAMETER, (Tfluid-Tamb)/I, [DegC/(W/m2)].
EFF=(I-Qlosses)/I.

Tfluid DegC	Tamb DegC	I W/m2	X	EFF	Tco DegC	Tci DegC	Tabs1 DegC	Tabs2 DegC	Tabs3 DegC	Tabs4 DegC	Tbin DegC	Tbout DegC	HEAT BALANCE Front W/m2	Back W/m2	GRASHOF AND NUSSELT NUMBERS Grf	Nuf	Grb	Nub
12.0	21.1	910	-.010	+0.908	23.5	23.4	17.91	14.32	12.0	12.1	13.2	18.8	-0.21	+0.4	209	1.0	50	1.0
16.5	21.1	910	-.005	+0.882	25.7	25.7	22.34	18.82	16.6	16.6	17.0	19.4	-0.20	+0.1	120	1.0	19	1.0
21.1	21.1	910	0.000	+0.856	27.9	27.9	26.76	23.32	21.1	21.1	20.9	20.0	-0.19	-0.3	40	1.0	7	1.0
25.6	21.1	910	0.005	+0.830	30.2	30.2	31.18	27.82	25.6	25.6	24.8	20.6	-0.19	-0.9	32	1.0	29	1.0
30.2	21.1	910	0.010	+0.803	32.5	32.5	35.59	32.32	30.2	30.1	28.7	21.1	-0.18	-0.0	96	1.0	48	1.0
34.7	21.1	910	0.015	+0.775	34.7	34.8	40.01	36.81	34.7	34.6	32.6	21.7	-0.17	+0.0	153	1.0	64	1.0
39.3	21.1	910	0.020	+0.747	37.0	37.1	44.42	41.31	39.2	39.2	36.5	22.3	-0.16	-0.0	204	1.0	76	1.0
43.8	21.1	910	0.025	+0.718	39.4	39.5	48.82	45.80	43.8	43.7	40.5	22.8	-0.15	-0.0	249	1.0	87	1.0
48.4	21.1	910	0.030	+0.689	41.7	41.8	53.23	50.30	48.3	48.2	44.5	23.4	-0.14	-0.0	289	1.0	95	1.0
52.9	21.1	910	0.035	+0.659	44.1	44.2	57.63	54.79	52.9	52.7	48.5	24.0	-0.13	-0.0	325	1.0	102	1.0
57.5	21.1	910	0.040	+0.629	46.4	46.6	62.03	59.28	57.4	57.2	52.6	24.6	-0.12	-0.0	356	1.0	107	1.0
62.1	21.1	910	0.045	+0.598	48.8	49.0	66.42	63.77	61.9	61.8	56.6	25.2	-0.10	-0.0	384	1.0	111	1.0
66.6	21.1	910	0.050	+0.567	51.2	51.4	70.81	68.25	66.5	66.3	60.7	25.8	-0.09	-0.0	409	1.0	113	1.0
71.2	21.1	910	0.055	+0.535	53.6	53.9	75.20	72.74	71.0	70.8	64.8	26.4	-0.08	-0.0	430	1.0	115	1.0
75.7	21.1	910	0.060	+0.502	56.0	56.3	79.58	77.23	75.5	75.3	68.9	26.9	-0.07	-0.0	449	1.0	117	1.0
80.3	21.1	910	0.065	+0.469	58.5	58.8	83.96	81.71	80.1	79.8	73.1	27.5	-0.06	-0.1	465	1.0	117	1.0
84.8	21.1	910	0.070	+0.435	60.9	61.3	88.34	86.19	84.6	84.3	77.2	28.1	-0.05	-0.1	479	1.0	117	1.0
89.4	21.1	910	0.075	+0.400	63.4	63.7	92.71	90.67	89.2	88.8	81.4	28.7	-0.04	-0.1	491	1.0	116	1.0
93.9	21.1	910	0.080	+0.365	65.9	66.3	97.08	95.15	93.7	93.4	85.6	29.3	-0.02	-0.1	502	1.0	115	1.0
98.4	21.1	910	0.085	+0.329	68.4	68.8	101.45	99.63	98.2	97.9	89.8	29.9	-0.01	-0.1	510	1.0	114	1.0
103.0	21.1	910	0.090	+0.293	70.9	71.3	105.81	104.10	102.8	102.4	94.0	30.5	-0.00	-0.2	517	1.0	113	1.0
107.5	21.1	910	0.095	+0.256	73.4	73.9	110.17	108.58	107.3	106.9	98.2	31.1	+0.01	-0.2	523	1.0	111	1.0
112.1	21.1	910	0.100	+0.218	76.0	76.4	114.52	113.05	111.8	111.4	102.5	31.7	+0.02	-0.2	527	1.0	109	1.0
116.6	21.1	910	0.105	+0.179	78.5	79.0	118.87	117.52	116.4	115.9	106.8	32.3	+0.03	-0.3	531	1.0	107	1.0
121.2	21.1	910	0.110	+0.140	81.1	81.6	123.22	121.99	120.9	120.5	111.0	32.9	+0.03	-0.3	533	1.0	104	1.0
125.7	21.1	910	0.115	+0.100	83.6	84.2	127.56	126.46	125.4	125.0	115.3	33.5	+0.04	-0.4	534	1.0	102	1.0
130.3	21.1	910	0.120	+0.059	86.2	86.8	131.89	130.93	130.0	129.5	119.6	34.1	+0.04	-0.5	535	1.0	100	1.0
134.8	21.1	910	0.125	+0.018	88.8	89.4	136.23	135.39	134.5	134.0	124.0	34.7	+0.04	-0.6	535	1.0	97	1.0

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COLLECTOR AND ENVIRONMENTAL FACTORS:

INSOLATION NORMAL TO COLLECTOR (W/SQ M)= 910
AMBIENT AIR TEMPERATURE (DEG C)= 21.1
COLLECTOR TILT ANGLE (DEG)= 45
EFFECTIVE SKY EMISSIVITY (f(Dew Pt))= .855
WIND SPEED (M/SEC)= 0

EMISSIVITY OF COVER= .88
TRANSMITTANCE OF COVER= .92
ABSORPTANCE OF COVER= .08
REFLECTANCE OF COVER= 0
CONDUCTIVITY OF COVER (W/M/DEG K)= .203
THICKNESS OF COVER (MM)= .203

RIB HEIGHT (DISTANCE BETWEEN 'COVER' AND ABSORBER), (cm) = .635
RADIANT TRANSFER VIEW FACTOR (ABSORBER TO COVER)= .6

ABSORBER TUBE O.D. (mm)= 6.35
ABSORBER SKIN THICKNESS (MM)= .718
CONDUCTIVITY OF ABSORBER SKIN (W/M/DEG K)= .1759
ABSORBER EMISSIVITY= .92
ABSORBER ABSORPTIVITY= .92

THICKNESS OF BACKING #1 (AIR WITH RIBS), (cm) = .635

THICKNESS OF BACKING #2 (PLASTIC), (mm) = 12.7
CONDUCTIVITY OF BACKING #2 (W/M/DEG K)= .018
EMISSIVITY OF BACKING #2 = .88
ABSORPTIVITY OF BACKING #2= .88
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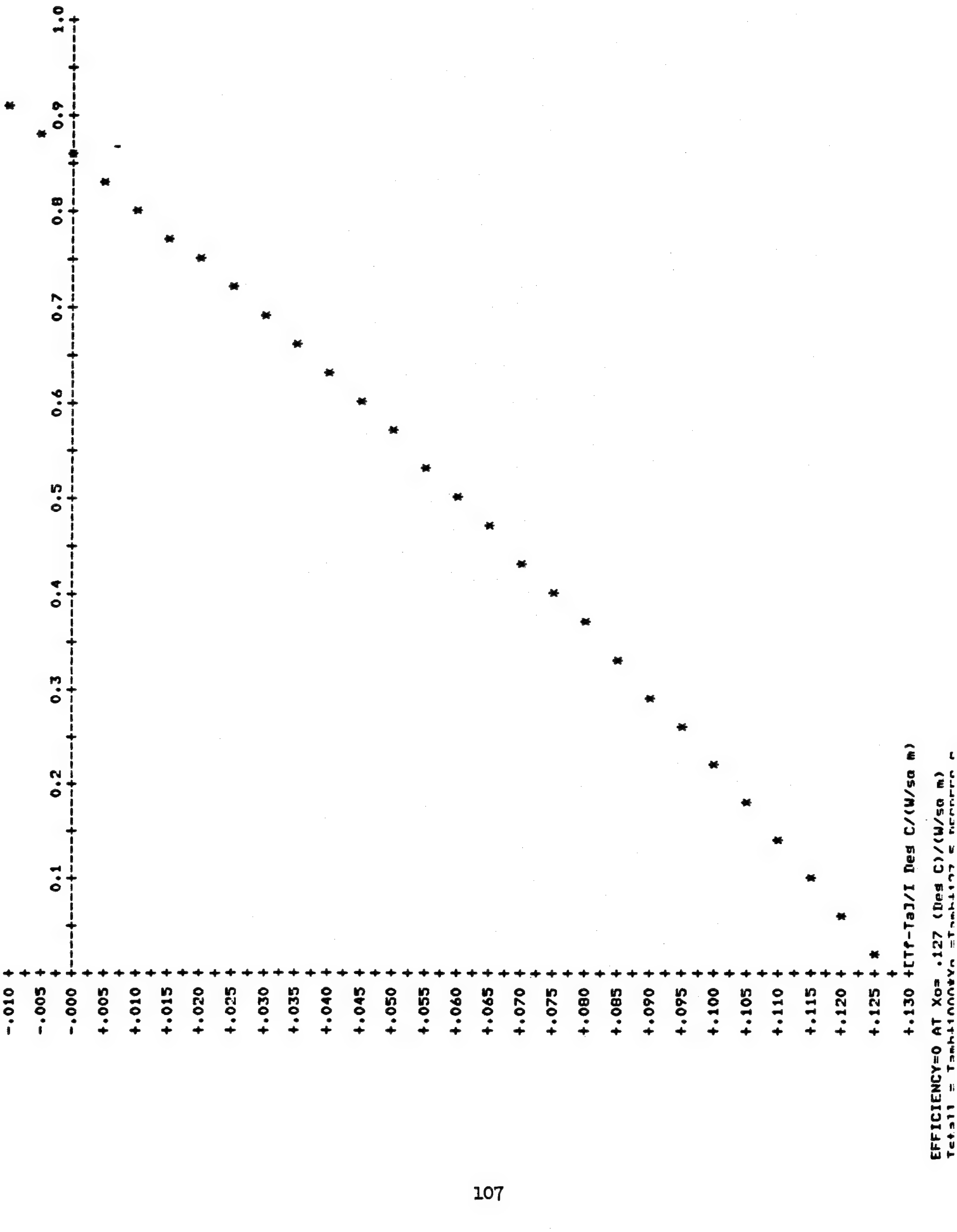


0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
-.010
-.005
-.000
+.005
+.010
+.015
+.020
+.025
+.030
+.035
+.040
+.045
+.050
+.055
+.060
+.065
+.070
+.075
+.080
+.085
+.090
+.095
+.100
+.105
+.110
+.115
+.120
+.125
+.130
[Tf-Ta]/I Deg C/(W/sq m)
EFFICIENCY=0 AT Xo= .127 (Deg C)/(W/sq m)

CASE 5

19.1 mm Height

25.4 mm Polyurethane Backing

0.0 Wind Velocity

NOTES: I=GLOBAL INSOLATION, [W/m2].
X=FLUID PARAMETER, (Tfluid-Tamb)/I, [DegC/(W/m2)].
EFF=(I-Qlosses)/I.

Tfluid DegC	Tamb DegC	I W/m2	X	EFF	Tco DegC	Tci DegC	Tabs1 DegC	Tabs2 DegC	Tabs3 DegC	Tabs4 DegC	Tbin DegC	Tbout DegC	HEAT BALANCE Front W/m2	HEAT BALANCE Back W/m2	FRONT AND BACK LOSSES Qfront W/m2	Qribf W/m2	Qback W/m2	Qribb W/m2
12.0	21.1	910	-.010	+0.904	23.5	23.4	17.91	14.32	12.0	12.0	12.7	19.2	-0.21	+0.5	-92	11	5	0
16.5	21.1	910	-.005	+0.881	25.7	25.7	22.34	18.82	16.6	16.6	16.8	19.5	-0.20	+0.2	-110	6	2	0
21.1	21.1	910	0.000	+0.857	27.9	27.9	26.76	23.32	21.1	21.1	21.0	19.9	-0.19	-0.3	-130	2	-1	-0
25.6	21.1	910	0.005	+0.833	30.2	30.2	31.18	27.82	25.6	25.6	25.1	20.3	-0.19	-1.0	-149	-2	-3	-0
30.2	21.1	910	0.010	+0.808	32.5	32.5	35.59	32.32	30.2	30.2	29.3	20.6	-0.18	-0.0	-169	-6	-6	-0
34.7	21.1	910	0.015	+0.782	34.7	34.8	40.01	36.81	34.7	34.7	33.5	20.9	-0.17	-0.0	-189	-10	-9	-0
39.3	21.1	910	0.020	+0.756	37.0	37.1	44.42	41.31	39.3	39.2	37.7	21.2	-0.16	-0.0	-210	-14	-12	-0
43.8	21.1	910	0.025	+0.730	39.4	39.5	48.82	45.80	43.8	43.8	41.9	21.6	-0.15	-0.0	-231	-18	-14	-0
48.4	21.1	910	0.030	+0.703	41.7	41.8	53.23	50.30	48.4	48.3	46.2	21.9	-0.14	-0.0	-253	-22	-17	-0
52.9	21.1	910	0.035	+0.676	44.1	44.2	57.63	54.79	52.9	52.8	50.4	22.2	-0.13	-0.0	-275	-26	-20	-0
57.5	21.1	910	0.040	+0.648	46.4	46.6	62.03	59.28	57.4	57.3	54.7	22.6	-0.12	-0.0	-298	-30	-23	-0
62.1	21.1	910	0.045	+0.619	48.8	49.0	66.42	63.77	62.0	61.9	59.0	22.9	-0.10	-0.0	-321	-33	-26	-0
66.6	21.1	910	0.050	+0.590	51.2	51.4	70.81	68.25	66.5	66.4	63.3	23.3	-0.09	-0.1	-345	-37	-28	-1
71.2	21.1	910	0.055	+0.560	53.6	53.9	75.20	72.74	71.1	70.9	67.6	23.6	-0.08	-0.1	-369	-41	-31	-1
75.7	21.1	910	0.060	+0.530	56.0	56.3	79.58	77.23	75.6	75.5	71.9	23.9	-0.07	-0.1	-394	-45	-34	-1
80.3	21.1	910	0.065	+0.499	58.5	58.8	83.96	81.71	80.2	80.0	76.2	24.3	-0.06	-0.1	-419	-48	-37	-1
84.8	21.1	910	0.070	+0.468	60.9	61.3	88.34	86.19	84.7	84.5	80.5	24.6	-0.05	-0.2	-445	-52	-40	-1
89.4	21.1	910	0.075	+0.436	63.4	63.7	92.71	90.67	89.2	89.1	84.9	25.0	-0.04	-0.2	-471	-56	-43	-1
93.9	21.1	910	0.080	+0.403	65.9	66.3	97.08	95.15	93.8	93.6	89.2	25.3	-0.02	-0.3	-498	-59	-46	-1
98.4	21.1	910	0.085	+0.370	68.4	68.8	101.45	99.63	98.3	98.1	93.6	25.6	-0.01	-0.4	-525	-63	-49	-1
103.0	21.1	910	0.090	+0.335	70.9	71.3	105.81	104.10	102.9	102.7	98.0	26.0	-0.00	-0.4	-553	-66	-51	-1
107.5	21.1	910	0.095	+0.301	73.4	73.9	110.17	108.58	107.4	107.2	102.3	26.3	+0.01	-0.5	-582	-70	-54	-1
112.1	21.1	910	0.100	+0.265	76.0	76.4	114.52	113.05	112.0	111.7	106.7	26.7	+0.02	-0.6	-611	-73	-57	-1
116.6	21.1	910	0.105	+0.229	78.5	79.0	118.87	117.52	116.5	116.2	111.1	27.0	+0.03	-0.7	-641	-77	-60	-1
121.2	21.1	910	0.110	+0.193	81.1	81.6	123.22	121.99	121.0	120.8	115.5	27.4	+0.03	-0.9	-671	-80	-63	-1
125.7	21.1	910	0.115	+0.156	83.6	84.2	127.56	126.46	125.6	125.3	120.0	27.6	+0.04	-0.0	-703	-83	-65	-1
130.3	21.1	910	0.120	+0.118	86.2	86.8	131.89	130.93	130.1	129.8	124.4	28.0	+0.04	-0.0	-734	-87	-68	-1
134.8	21.1	910	0.125	+0.079	88.8	89.4	136.23	135.39	134.7	134.4	128.8	28.3	+0.04	-0.0	-767	-90	-71	-1
139.4	21.1	910	0.130	+0.040	91.4	92.1	140.55	139.85	139.2	138.9	133.2	28.6	+0.04	-0.0	-800	-93	-74	-1

EFF= I-(Qlosses)/I

Tfluid DesC	Tamb DesC	I W/m2	X	EFF	Tco DesC	Tci DesC	Tabs1 DesC	Tabs2 DesC	Tabs3 DesC	Tabs4 DesC	Thin DesC	Tbout DesC	HEAT BALANCE Front W/m2	Back W/m2	GRASHOF AND NUSSL NUMBERS Grf	Nuf	Grb	Nub
12.0	21.1	910	-.010	+0.904	23.5	23.4	17.91	14.32	12.0	12.0	12.7	19.2	-0.21	+0.5	209	1.0	29	1.0
16.5	21.1	910	-.005	+0.881	25.7	25.7	22.34	18.82	16.6	16.6	16.8	19.5	-0.20	+0.2	120	1.0	11	1.0
21.1	21.1	910	0.000	+0.857	27.9	27.9	26.76	23.32	21.1	21.1	21.0	19.9	-0.19	-0.3	40	1.0	4	1.0
25.6	21.1	910	0.005	+0.833	30.2	30.2	31.18	27.82	25.6	25.6	25.1	20.3	-0.19	-1.0	32	1.0	17	1.0
30.2	21.1	910	0.010	+0.808	32.5	32.5	35.59	32.32	30.2	30.2	29.3	20.6	-0.18	-0.0	96	1.0	28	1.0
34.7	21.1	910	0.015	+0.782	34.7	34.8	40.01	36.81	34.7	34.7	33.5	20.9	-0.17	-0.0	153	1.0	36	1.0
39.3	21.1	910	0.020	+0.756	37.0	37.1	44.42	41.31	39.3	39.2	37.7	21.2	-0.16	-0.0	204	1.0	43	1.0
43.8	21.1	910	0.025	+0.730	39.4	39.5	48.82	45.80	43.8	43.8	41.9	21.6	-0.15	-0.0	249	1.0	49	1.0
48.4	21.1	910	0.030	+0.703	41.7	41.8	53.23	50.30	48.4	48.3	46.2	21.9	-0.14	-0.0	289	1.0	54	1.0
52.9	21.1	910	0.035	+0.676	44.1	44.2	57.63	54.79	52.9	52.8	50.4	22.2	-0.13	-0.0	325	1.0	57	1.0
57.5	21.1	910	0.040	+0.648	46.4	46.6	62.03	59.28	57.4	57.3	54.7	22.6	-0.12	-0.0	356	1.0	60	1.0
62.1	21.1	910	0.045	+0.619	48.8	49.0	66.42	63.77	62.0	61.9	59.0	22.9	-0.10	-0.0	384	1.0	62	1.0
66.6	21.1	910	0.050	+0.590	51.2	51.4	70.81	68.25	66.5	66.4	63.3	23.3	-0.09	-0.1	409	1.0	63	1.0
71.2	21.1	910	0.055	+0.560	53.6	53.9	75.20	72.74	71.1	70.9	67.6	23.6	-0.08	-0.1	430	1.0	64	1.0
75.7	21.1	910	0.060	+0.530	56.0	56.3	79.58	77.23	75.6	75.5	71.9	23.9	-0.07	-0.1	449	1.0	65	1.0
80.3	21.1	910	0.065	+0.499	58.5	58.8	83.96	81.71	80.2	80.0	76.2	24.3	-0.06	-0.1	465	1.0	65	1.0
84.8	21.1	910	0.070	+0.468	60.9	61.3	88.34	86.19	84.7	84.5	80.5	24.6	-0.05	-0.2	479	1.0	65	1.0
89.4	21.1	910	0.075	+0.436	63.4	63.7	92.71	90.67	89.2	89.1	84.9	25.0	-0.04	-0.2	491	1.0	64	1.0
93.9	21.1	910	0.080	+0.403	65.9	66.3	97.08	95.15	93.8	93.6	89.2	25.3	-0.02	-0.3	502	1.0	63	1.0
98.4	21.1	910	0.085	+0.370	68.4	68.8	101.45	99.63	98.3	98.1	93.6	25.6	-0.01	-0.4	510	1.0	63	1.0
103.0	21.1	910	0.090	+0.335	70.9	71.3	105.81	104.10	102.9	102.7	98.0	26.0	-0.00	-0.4	517	1.0	62	1.0
107.5	21.1	910	0.095	+0.301	73.4	73.9	110.17	108.58	107.4	107.2	102.3	26.3	+0.01	-0.5	523	1.0	60	1.0
112.1	21.1	910	0.100	+0.265	76.0	76.4	114.52	113.05	112.0	111.7	106.7	26.7	+0.02	-0.6	527	1.0	59	1.0
116.6	21.1	910	0.105	+0.229	78.5	79.0	118.87	117.52	116.5	116.2	111.1	27.0	+0.03	-0.7	531	1.0	58	1.0
121.2	21.1	910	0.110	+0.193	81.1	81.6	123.22	121.99	121.0	120.8	115.5	27.4	+0.03	-0.9	533	1.0	57	1.0
125.7	21.1	910	0.115	+0.156	83.6	84.2	127.56	126.46	125.6	125.3	120.0	27.6	+0.04	-0.0	534	1.0	55	1.0
130.3	21.1	910	0.120	+0.118	86.2	86.8	131.89	130.93	130.1	129.8	124.4	28.0	+0.04	-0.0	535	1.0	54	1.0
134.8	21.1	910	0.125	+0.079	88.8	89.4	136.23	135.39	134.7	134.4	128.8	28.3	+0.04	-0.0	535	1.0	52	1.0
139.4	21.1	910	0.130	+0.040	91.4	92.1	140.55	139.85	139.2	138.9	133.2	28.6	+0.04	-0.0	534	1.0	51	1.0

COLLECTOR AND ENVIRONMENTAL FACTORS:

INSOLATION NORMAL TO COLLECTOR (W/SQ M)= 910
AMBIENT AIR TEMPERATURE (DEG C)= 21.1
COLLECTOR TILT ANGLE (DEG)= 45
EFFECTIVE SKY EMISSIVITY (f(Dew Pt))= .855
WIND SPEED (M/SEC)= 0

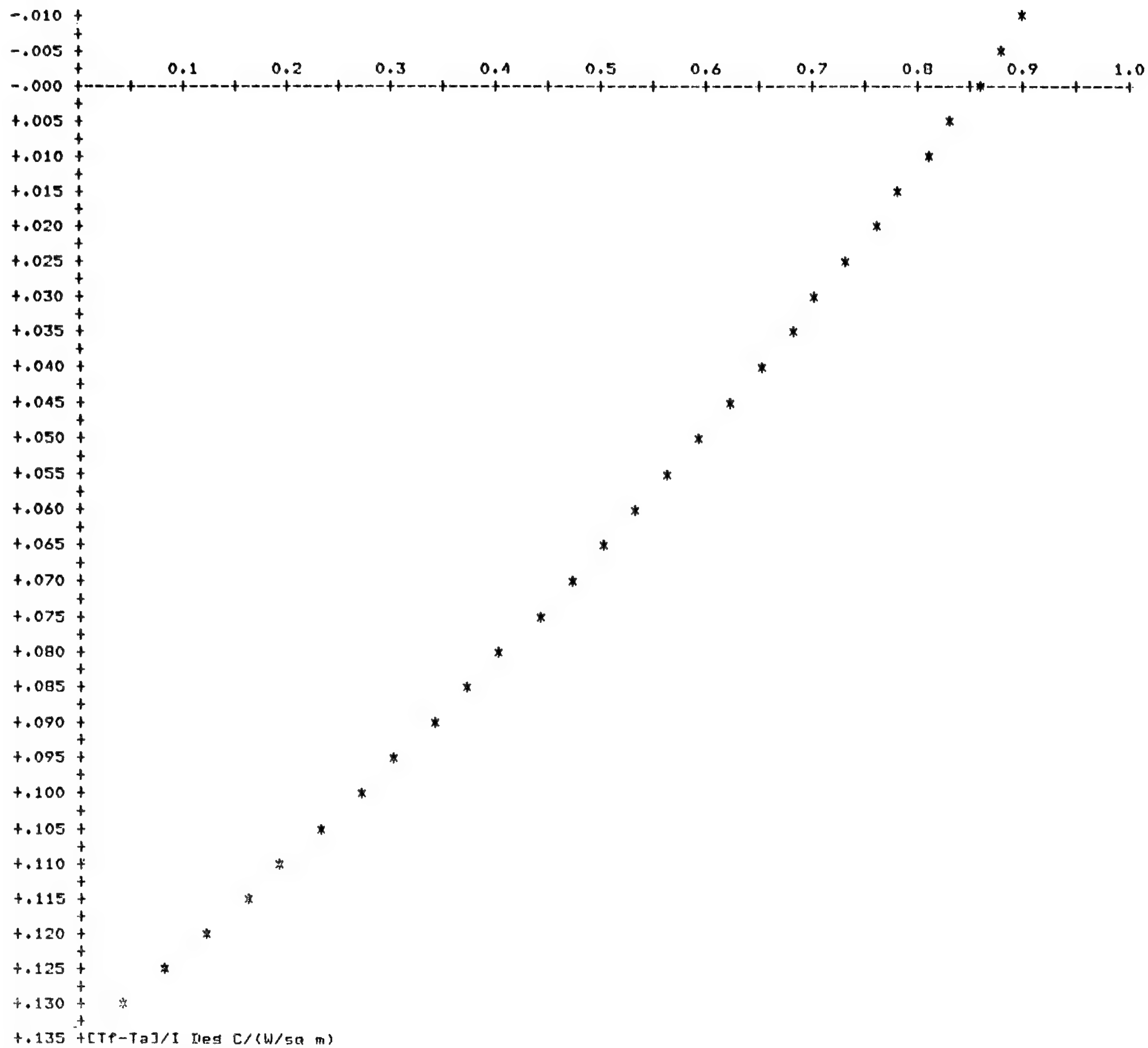
EMISSIVITY OF COVER= .88
TRANSMITTANCE OF COVER= .92
ABSORPTANCE OF COVER= .08
REFLECTANCE OF COVER= 0
CONDUCTIVITY OF COVER (W/M/DEG K)= .203
THICKNESS OF COVER (MM)= .203

RIB HEIGHT (DISTANCE BETWEEN 'COVER' AND ABSORBER), (cm) = .635
RADIANT TRANSFER VIEW FACTOR (ABSORBER TO COVER)= .6

ABSORBER TUBE O.D. (mm)= 6.35
ABSORBER SKIN THICKNESS (MM)= .718
CONDUCTIVITY OF ABSORBER SKIN (W/M/DEG K)= .1759
ABSORBER EMISSIVITY= .92
ABSORBER ABSORPTIVITY= .92

THICKNESS OF BACKING #1 (AIR WITH RIBS), (cm) = .635

THICKNESS OF BACKING #2 (PLASTIC), (mm) = 25.4
CONDUCTIVITY OF BACKING #2 (W/M/DEG K)= .018
EMISSIVITY OF BACKING #2 = .88
ABSORPTIVITY OF BACKING #2= .88



EFFICIENCY=0 AT Xo= .135 (Deg C)/(W/sq m)
Tstall = Tamb+1000*Xo =Tamb+135.0 DEGREES C.

CASE 6

Stall Sample Comparison
22.2 mm Height
25.4 mm Polyurethane Backing
0.2 m/s Wind Velocity

NOTES: I=GLOBAL INSOLATION, [W/m2].
X=FLUID PARAMETER, (Tfluid-Tamb)/I, [DegC/(W/m2)].
EFF=(I-Qlosses)/I.

Tfluid DegC	Tamb DegC	I W/m2	X	EFF	Tco DegC	Tci DegC	Tabs1 DegC	Tabs2 DegC	Tabs3 DegC	Tabs4 DegC	Tbin DegC	Tbout DegC	HEAT BALANCE Front W/m2	HEAT BALANCE Back W/m2	FRONT AND BACK LOSSES Qfront W/m2	Qribf W/m2	Qback W/m2	Qribb W/m2
28.4	37.5	913	-.010	+0.900	39.8	39.8	34.26	30.69	28.4	28.4	29.4	35.5	-0.12	+0.5	-98	5	6	0
32.9	37.5	913	-.005	+0.875	41.7	41.7	38.70	35.20	32.9	33.0	33.4	35.9	-0.12	+0.2	-117	3	3	0
37.5	37.5	913	0.000	+0.849	43.6	43.6	43.13	39.71	37.5	37.5	37.3	36.3	-0.12	-0.4	-137	0	-1	-0
42.1	37.5	913	0.005	+0.823	45.5	45.5	47.56	44.22	42.0	42.0	41.3	36.7	-0.11	-0.0	-157	-2	-5	-0
46.6	37.5	913	0.010	+0.796	47.5	47.5	51.98	48.73	46.6	46.6	45.3	37.1	-0.11	-0.0	-177	-4	-9	-0
51.2	37.5	913	0.015	+0.769	49.4	49.5	56.41	53.24	51.2	51.1	49.4	37.4	-0.11	-0.0	-198	-7	-13	-0
55.8	37.5	913	0.020	+0.741	51.4	51.5	60.82	57.74	55.7	55.6	53.4	37.8	-0.10	-0.0	-220	-9	-17	-0
60.3	37.5	913	0.025	+0.713	53.5	53.5	65.24	62.25	60.3	60.2	57.5	38.2	-0.10	-0.0	-241	-12	-21	-0
64.9	37.5	913	0.030	+0.684	55.5	55.6	69.65	66.75	64.8	64.7	61.6	38.6	-0.09	-0.0	-264	-14	-24	-0
69.4	37.5	913	0.035	+0.654	57.6	57.7	74.06	71.25	69.4	69.2	65.8	39.0	-0.08	-0.0	-287	-16	-28	-0
74.0	37.5	913	0.040	+0.624	59.7	59.8	78.47	75.76	73.9	73.8	69.9	39.4	-0.08	-0.0	-310	-18	-32	-1
78.6	37.5	913	0.045	+0.594	61.8	61.9	82.87	80.26	78.5	78.3	74.1	39.8	-0.07	-0.0	-334	-21	-36	-1
83.1	37.5	913	0.050	+0.562	63.9	64.0	87.27	84.75	83.0	82.9	78.3	40.2	-0.06	-0.0	-359	-23	-40	-1
87.7	37.5	913	0.055	+0.530	66.1	66.2	91.66	89.25	87.6	87.4	82.5	40.6	-0.05	-0.1	-384	-25	-45	-1
92.3	37.5	913	0.060	+0.497	68.2	68.4	96.05	93.75	92.1	91.9	86.7	41.0	-0.04	-0.1	-410	-27	-49	-1
96.8	37.5	913	0.065	+0.464	70.4	70.6	100.44	98.24	96.7	96.5	90.9	41.4	-0.02	-0.1	-436	-29	-53	-1
101.4	37.5	913	0.070	+0.430	72.6	72.8	104.82	102.73	101.2	101.0	95.2	41.8	+0.01	-0.1	-463	-31	-57	-1
105.9	37.5	913	0.075	+0.396	74.9	75.1	109.20	107.22	105.8	105.5	99.4	42.2	+0.00	-0.2	-491	-34	-61	-1
110.5	37.5	913	0.080	+0.360	77.1	77.4	113.57	111.71	110.3	110.1	103.7	42.6	-0.07	-0.2	-519	-36	-65	-1
115.1	37.5	913	0.085	+0.324	79.4	79.7	117.94	116.20	114.9	114.6	108.0	43.0	+0.01	-0.3	-548	-38	-69	-1
119.6	37.5	913	0.090	+0.287	81.7	82.0	122.30	120.68	119.4	119.1	112.3	43.5	+0.02	-0.3	-577	-40	-74	-1
124.2	37.5	913	0.095	+0.249	84.1	84.4	126.66	125.16	124.0	123.7	116.6	43.9	+0.02	-0.4	-608	-42	-78	-1
128.8	37.5	913	0.100	+0.211	86.4	86.7	131.02	129.65	128.5	128.2	121.0	44.3	+0.03	-0.4	-639	-44	-82	-1
133.3	37.5	913	0.105	+0.171	88.8	89.1	135.37	134.13	133.1	132.7	125.3	44.7	+0.03	-0.5	-670	-45	-86	-1
137.9	37.5	913	0.110	+0.131	91.2	91.5	139.72	138.60	137.6	137.3	129.7	45.1	+0.03	-0.6	-702	-47	-91	-1
142.4	37.5	913	0.115	+0.091	93.6	93.9	144.06	143.08	142.2	141.8	134.0	45.5	+0.03	-0.7	-735	-49	-95	-1
147.0	37.5	913	0.120	+0.049	96.0	96.4	148.39	147.55	146.8	146.4	138.4	45.9	+0.03	-0.9	-769	-51	-99	-1
151.6	37.5	913	0.125	+0.007	98.4	98.8	152.73	152.03	151.3	150.9	142.8	46.3	+0.02	-1.0	-803	-53	-104	-1

NOTES: I=GLOBAL INSOLATION, [W/m2].
X=FLUID PARAMETER, (Tfluid-Tamb)/I, [DegC/(W/m2)].
EFF=(I-Qlosses)/I.

Tfluid DegC	Tamb DegC	I W/m2	X	EFF	Tco DegC	Tci DegC	Tabs1 DegC	Tabs2 DegC	Tabs3 DegC	Tabs4 DegC	Tbin DegC	Tbout DegC	HEAT BALANCE Front W/m2	Back W/m2	GRASHOF AND Grf	Nuf	NUSSELT NUMBERS Grb	Nub
28.4	37.5	913	-.010	+0.900	39.8	39.8	34.26	30.69	28.4	28.4	29.4	35.5	-0.12	+0.5	318	1.0	64	1.0
32.9	37.5	913	-.005	+0.875	41.7	41.7	38.70	35.20	32.9	33.0	33.4	35.9	-0.12	+0.2	164	1.0	24	1.0
37.5	37.5	913	0.000	+0.849	43.6	43.6	43.13	39.71	37.5	37.5	37.3	36.3	-0.12	-0.4	24	1.0	9	1.0
42.1	37.5	913	0.005	+0.823	45.5	45.5	47.56	44.22	42.0	42.0	41.3	36.7	-0.11	-0.0	102	1.0	38	1.0
46.6	37.5	913	0.010	+0.796	47.5	47.5	51.98	48.73	46.6	46.6	45.3	37.1	-0.11	-0.0	216	1.0	62	1.0
51.2	37.5	913	0.015	+0.769	49.4	49.5	56.41	53.24	51.2	51.1	49.4	37.4	-0.11	-0.0	318	1.0	82	1.0
55.8	37.5	913	0.020	+0.741	51.4	51.5	60.82	57.74	55.7	55.6	53.4	37.8	-0.10	-0.0	411	1.0	99	1.0
60.3	37.5	913	0.025	+0.713	53.5	53.5	65.24	62.25	60.3	60.2	57.5	38.2	-0.10	-0.0	494	1.0	112	1.0
64.9	37.5	913	0.030	+0.684	55.5	55.6	69.65	66.75	64.8	64.7	61.6	38.6	-0.09	-0.0	568	1.0	123	1.0
69.4	37.5	913	0.035	+0.654	57.6	57.7	74.06	71.25	69.4	69.2	65.8	39.0	-0.08	-0.0	635	1.0	132	1.0
74.0	37.5	913	0.040	+0.624	59.7	59.8	78.47	75.76	73.9	73.8	69.9	39.4	-0.08	-0.0	695	1.0	139	1.0
78.6	37.5	913	0.045	+0.594	61.8	61.9	82.87	80.26	78.5	78.3	74.1	39.8	-0.07	-0.0	748	1.0	144	1.0
83.1	37.5	913	0.050	+0.562	63.9	64.0	87.27	84.75	83.0	82.9	78.3	40.2	-0.06	-0.0	795	1.0	148	1.0
87.7	37.5	913	0.055	+0.530	66.1	66.2	91.66	89.25	87.6	87.4	82.5	40.6	-0.05	-0.1	837	1.0	151	1.0
92.3	37.5	913	0.060	+0.497	68.2	68.4	96.05	93.75	92.1	91.9	86.7	41.0	-0.04	-0.1	874	1.0	152	1.0
96.8	37.5	913	0.065	+0.464	70.4	70.6	100.44	98.24	96.7	96.5	90.9	41.4	-0.02	-0.1	906	1.0	153	1.0
101.4	37.5	913	0.070	+0.430	72.6	72.8	104.82	102.73	101.2	101.0	95.2	41.8	+0.01	-0.1	934	1.0	153	1.0
105.9	37.5	913	0.075	+0.396	74.9	75.1	109.20	107.22	105.8	105.5	99.4	42.2	+0.00	-0.2	959	1.0	153	1.0
110.5	37.5	913	0.080	+0.360	77.1	77.4	113.57	111.71	110.3	110.1	103.7	42.6	-0.07	-0.2	980	1.0	152	1.0
115.1	37.5	913	0.085	+0.324	79.4	79.7	117.94	116.20	114.9	114.6	108.0	43.0	+0.01	-0.3	997	1.0	150	1.0
119.6	37.5	913	0.090	+0.287	81.7	82.0	122.30	120.68	119.4	119.1	112.3	43.5	+0.02	-0.3	1012	1.0	148	1.0
124.2	37.5	913	0.095	+0.249	84.1	84.4	126.66	125.16	124.0	123.7	116.6	43.9	+0.02	-0.4	1023	1.0	146	1.0
128.8	37.5	913	0.100	+0.211	86.4	86.7	131.02	129.65	128.5	128.2	121.0	44.3	+0.03	-0.4	1033	1.0	143	1.0
133.3	37.5	913	0.105	+0.171	88.8	89.1	135.37	134.13	133.1	132.7	125.3	44.7	+0.03	-0.5	1041	1.0	141	1.0
137.9	37.5	913	0.110	+0.131	91.2	91.5	139.72	138.60	137.6	137.3	129.7	45.1	+0.03	-0.6	1046	1.0	138	1.0
142.4	37.5	913	0.115	+0.091	93.6	93.9	144.06	143.08	142.2	141.8	134.0	45.5	+0.03	-0.7	1050	1.0	135	1.0
147.0	37.5	913	0.120	+0.049	96.0	96.4	148.39	147.55	146.8	146.4	138.4	45.9	+0.03	-0.9	1053	1.0	132	1.0
151.6	37.5	913	0.125	+0.007	98.4	98.8	152.73	152.03	151.3	150.9	142.8	46.3	+0.02	-1.0	1054	1.0	129	1.0

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COLLECTOR AND ENVIRONMENTAL FACTORS:

INSOLATION NORMAL TO COLLECTOR (W/SQ M)= 912.6
AMBIENT AIR TEMPERATURE (DEG C)= 37.5
COLLECTOR TILT ANGLE (DEG)= 45
EFFECTIVE SKY EMISSIVITY (f(Dew Pt))= .855
WIND SPEED (M/SEC)= .2

EMISSIVITY OF COVER= .88
TRANSMITTANCE OF COVER= .92
ABSORPTANCE OF COVER= .08
REFLECTANCE OF COVER= 0
CONDUCTIVITY OF COVER (W/M/DEG K)= .203
THICKNESS OF COVER (MM)= .127

RIB HEIGHT (DISTANCE BETWEEN 'COVER' AND ABSORBER), (cm) = .794
RADIANT TRANSFER VIEW FACTOR (ABSORBER TO COVER)= .6

ABSORBER TUBE O.D. (mm)= 6.35
ABSORBER SKIN THICKNESS (MM)= .718
CONDUCTIVITY OF ABSORBER SKIN (W/M/DEG K)= .1759
ABSORBER EMISSIVITY= .92
ABSORBER ABSORPTIVITY= .92


THICKNESS OF BACKING #1 (AIR WITH RIBS), (cm) = .794


THICKNESS OF BACKING #2 (PLASTIC), (mm) = 25.4
CONDUCTIVITY OF BACKING #2 (W/M/DEG K)= .027
EMISSIVITY OF BACKING #2 = .88
ABSORPTIVITY OF BACKING #2= .88
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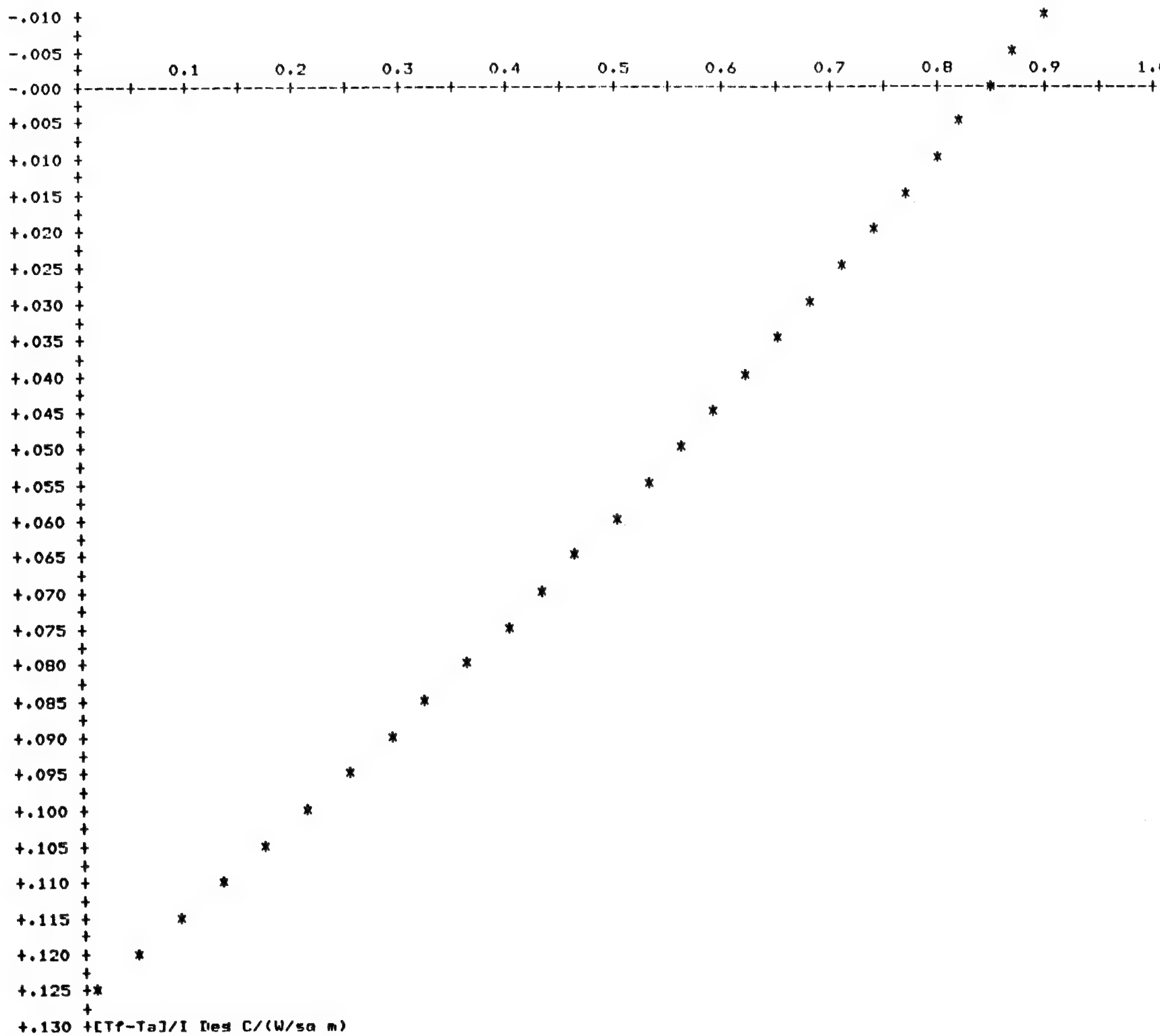

EFFICIENCY=0 AT Xo= .088 (Deg C)/(W/sq m)
Tstall = Tamb+1000*Xo =Tamb+ 88.3 DEGREES C.

CASE 7

19.1 mm Height

Air Backing

2.2 m/s Wind Velocity

```
0970  REM
09

ABORT

0960  DATA .00635,910,21.1,45,.855,2.235
KIL-COAXDATA
SAV-COAXDATA
RUN
COAXDATA

PRINT GRASHOF AND NUSSELT NUMBERS, OR LOSSES (N/L)? L

NOTES:  I=GLOBAL INSOLATION, [W/m2].
        X=FLUID PARAMETER, (Tfluid-Tamb)/I, [DegC/(W/m2)].
        EFF=(I-Qlosses)/I.
```

													HEAT BALANCE		FRONT AND BACK LOSSES			
Tfluid DegC	Tamb DegC	I W/m2	X	EFF	Tco DegC	Tci DegC	Tabs1 DegC	Tabs2 DegC	Tabs3 DegC	Tabs4 DegC	Tbin DegC	Tbout DegC	Front W/m2	Back W/m2	Qfront W/m2	Qribf W/m2	Qback W/m2	Qribb W/m2
12.0	21.1	910	-.010	+0.943	22.6	22.6	17.87	14.30	12.1	12.3	17.8	17.8	-0.03	+0.5	-99	9	47	10
16.5	21.1	910	-.005	+0.888	24.0	24.0	22.25	18.79	16.6	16.7	19.2	19.2	-0.03	+0.2	-124	3	22	5
21.1	21.1	910	0.000	+0.832	25.5	25.5	26.62	23.27	21.1	21.1	20.7	20.7	-0.03	-0.2	-150	-2	-3	-1
25.6	21.1	910	0.005	+0.775	27.0	27.0	31.00	27.75	25.6	25.5	22.2	22.2	-0.03	-0.6	-176	-8	-29	-6
30.2	21.1	910	0.010	+0.716	28.5	28.5	35.37	32.23	30.1	29.8	23.7	23.6	-0.02	-0.0	-203	-13	-55	-12
34.7	21.1	910	0.015	+0.657	30.0	30.1	39.73	36.71	34.5	34.2	25.2	25.1	-0.02	-0.0	-230	-19	-82	-17
39.3	21.1	910	0.020	+0.596	31.5	31.6	44.10	41.18	39.0	38.6	26.8	26.7	-0.02	+0.0	-258	-24	-109	-23
43.8	21.1	910	0.025	+0.535	33.1	33.2	48.45	45.66	43.5	42.9	28.3	28.2	-0.01	-0.0	-286	-29	-137	-28
48.4	21.1	910	0.030	+0.472	34.6	34.8	52.81	50.13	48.0	47.3	29.9	29.8	-0.00	-0.0	-315	-35	-165	-33
52.9	21.1	910	0.035	+0.408	36.2	36.5	57.16	54.60	52.4	51.6	31.6	31.4	+0.00	-0.0	-345	-40	-194	-39
57.5	21.1	910	0.040	+0.343	37.9	38.1	61.51	59.08	56.9	56.0	33.2	33.0	+0.01	+0.0	-375	-45	-223	-44
62.1	21.1	910	0.045	+0.277	39.5	39.8	65.86	63.54	61.4	60.3	34.9	34.6	+0.01	-0.0	-405	-50	-253	-49
66.6	21.1	910	0.050	+0.210	41.2	41.5	70.20	68.01	65.9	64.7	36.5	36.3	+0.02	-0.0	-436	-55	-283	-54
71.2	21.1	910	0.055	+0.141	42.9	43.2	74.54	72.48	70.3	69.0	38.2	37.9	+0.02	-0.0	-468	-60	-314	-59
75.7	21.1	910	0.060	+0.071	44.6	44.9	78.87	76.94	74.8	73.4	40.0	39.6	+0.02	-0.0	-500	-65	-346	-64

RUN
COAXDATA

PRINT GRASHOF AND NUSSELT NUMBERS, OR LOSSES (N/L)? N

NOTES: I=GLOBAL INSOLATION, [W/m2].
X=FLUID PARAMETER, (Tfluid-Tamb)/I, [DegC/(W/m2)].
EFF=(I-Qlosses)/I.

Tfluid DegC	Tamb DegC	I W/m2	X	EFF	Tco DegC	Tci DegC	Tabs1 DegC	Tabs2 DegC	Tabs3 DegC	Tabs4 DegC	Tbin DegC	Tbout DegC	HEAT BALANCE Front W/m2	HEAT BALANCE Back W/m2	GRASHOF AND NUSSELT NUMBERS Grf	Nuf	Grb	Nub
12.0	21.1	910	-.010	+0.943	22.6	22.6	17.87	14.30	12.1	12.3	17.8	17.8	-0.03	+0.5	180	1.0	227	1.0
16.5	21.1	910	-.005	+0.888	24.0	24.0	22.25	18.79	16.6	16.7	19.2	19.2	-0.03	+0.2	65	1.0	100	1.0
21.1	21.1	910	0.000	+0.832	25.5	25.5	26.62	23.27	21.1	21.1	20.7	20.7	-0.03	-0.2	39	1.0	14	1.0
25.6	21.1	910	0.005	+0.775	27.0	27.0	31.00	27.75	25.6	25.5	22.2	22.2	-0.03	-0.6	133	1.0	118	1.0
30.2	21.1	910	0.010	+0.716	28.5	28.5	35.37	32.23	30.1	29.8	23.7	23.6	-0.02	-0.0	218	1.0	212	1.0
34.7	21.1	910	0.015	+0.657	30.0	30.1	39.73	36.71	34.5	34.2	25.2	25.1	-0.02	-0.0	294	1.0	296	1.0
39.3	21.1	910	0.020	+0.596	31.5	31.6	44.10	41.18	39.0	38.6	26.8	26.7	-0.02	+0.0	363	1.0	371	1.0
43.8	21.1	910	0.025	+0.535	33.1	33.2	48.45	45.66	43.5	42.9	28.3	28.2	-0.01	-0.0	425	1.0	439	1.0
48.4	21.1	910	0.030	+0.472	34.6	34.8	52.81	50.13	48.0	47.3	29.9	29.8	-0.00	-0.0	481	1.0	500	1.0
52.9	21.1	910	0.035	+0.408	36.2	36.5	57.16	54.60	52.4	51.6	31.6	31.4	+0.00	-0.0	531	1.0	554	1.0
57.5	21.1	910	0.040	+0.343	37.9	38.1	61.51	59.08	56.9	56.0	33.2	33.0	+0.01	+0.0	575	1.0	603	1.0
62.1	21.1	910	0.045	+0.277	39.5	39.8	65.86	63.54	61.4	60.3	34.9	34.6	+0.01	-0.0	615	1.0	646	1.0
66.6	21.1	910	0.050	+0.210	41.2	41.5	70.20	68.01	65.9	64.7	36.5	36.3	+0.02	-0.0	650	1.0	684	1.0
71.2	21.1	910	0.055	+0.141	42.9	43.2	74.54	72.48	70.3	69.0	38.2	37.9	+0.02	-0.0	681	1.0	717	1.0
75.7	21.1	910	0.060	+0.071	44.6	44.9	78.87	76.94	74.8	73.4	40.0	39.6	+0.02	-0.0	708	1.0	747	1.0

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COLLECTOR AND ENVIRONMENTAL FACTORS:

INSOLATION NORMAL TO COLLECTOR (W/SQ M)= 910
AMBIENT AIR TEMPERATURE (DEG C)= 21.1
COLLECTOR TILT ANGLE (DEG)= 45
EFFECTIVE SKY EMISSIVITY (f(Dew Pt))= .855
WIND SPEED (M/SEC)= 2.235

EMISSIVITY OF COVER= .88
TRANSMITTANCE OF COVER= .92
ABSORPTANCE OF COVER= .08
REFLECTANCE OF COVER= 0
CONDUCTIVITY OF COVER (W/M/DEG K)= .203
THICKNESS OF COVER (MM)= .203

RIB HEIGHT (DISTANCE BETWEEN 'COVER' AND ABSORBER), (cm) = .635
RADIANT TRANSFER VIEW FACTOR (ABSORBER TO COVER)= .6

ABSORBER TUBE O.D. (mm)= 6.35
ABSORBER SKIN THICKNESS (MM)= .718
CONDUCTIVITY OF ABSORBER SKIN (W/M/DEG K)= .1759
ABSORBER EMISSIVITY= .92
ABSORBER ABSORPTIVITY= .92

THICKNESS OF BACKING #1 (AIR WITH RIBS), (cm) = .635

THICKNESS OF BACKING #2 (PLASTIC), (mm) = .203
CONDUCTIVITY OF BACKING #2 (W/M/DEG K)= .203
EMISSIVITY OF BACKING #2 = .88
ABSORPTIVITY OF BACKING #2= .88
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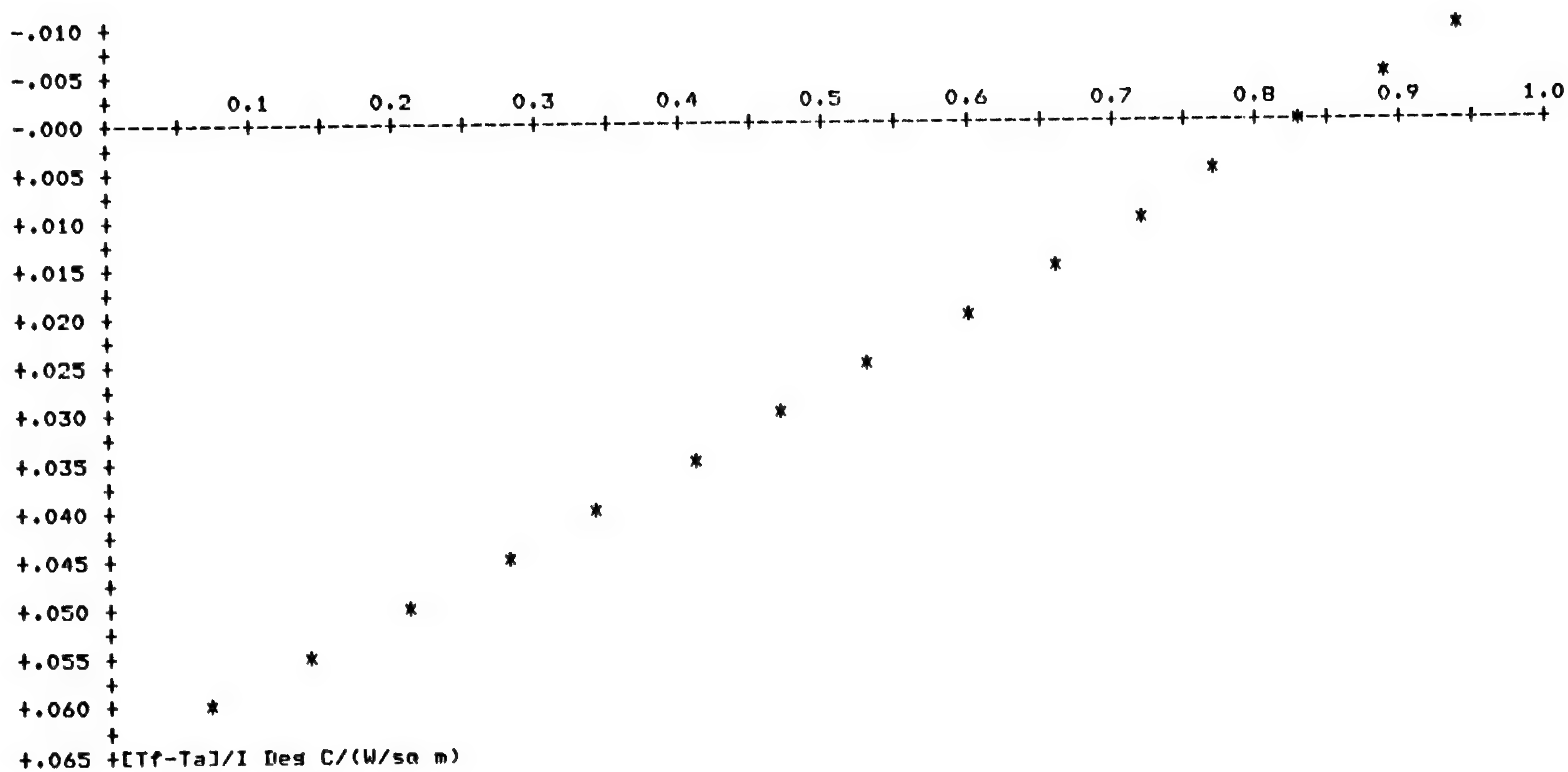
COLLECTOR EFFICIENCY



EFFICIENCY=0 AT Xo= .065 (Deg C)/(W/sq m)
Tstall = Tamb+1000*Xo =Tamb+ 65.0 DEGREES C.

CASE 8

19.1 mm Height
Air Backing
4.5 m/s Wind Velocity

RUN
COAXDATA

PRINT GRASHOF AND NUSSELT NUMBERS, OR LOSSES (N/L)? L

NOTES: I=GLOBAL INSOLATION, [W/m2].
X=FLUID PARAMETER, (Tfluid-Tamb)/I, [DegC/(W/m2)].
EFF=(I-Qlosses)/I.

Tfluid DegC	Tamb DegC	I W/m2	X	EFF	Tco DegC	Tci DegC	Tabs1 DegC	Tabs2 DegC	Tabs3 DegC	Tabs4 DegC	Tbin DegC	Tbout DegC	HEAT BALANCE Front W/m2	Back W/m2	FRONT AND BACK LOSSES Qfront W/m2	Qribf W/m2	Qback W/m2	Qribb W/m2
12.0	21.1	910	-.010	+0.947	22.2	22.2	17.84	14.29	12.1	12.4	18.6	18.7	+0.01	+0.7	-102	8	54	12
16.5	21.1	910	-.005	+0.885	23.3	23.3	22.20	18.77	16.6	16.7	19.7	19.7	+0.01	+0.4	-130	2	26	6
21.1	21.1	910	0.000	+0.822	24.3	24.4	26.56	23.24	21.1	21.1	20.8	20.8	+0.01	-0.1	-160	-4	-2	-1
25.6	21.1	910	0.005	+0.758	25.4	25.5	30.91	27.71	25.6	25.4	21.9	21.9	+0.01	-0.8	-189	-10	-31	-7
30.2	21.1	910	0.010	+0.692	26.5	26.6	35.26	32.19	30.0	29.8	23.0	23.0	+0.01	-0.0	-219	-17	-61	-13
34.7	21.1	910	0.015	+0.625	27.7	27.8	39.60	36.65	34.5	34.1	24.2	24.1	+0.02	-0.0	-250	-23	-91	-19
39.3	21.1	910	0.020	+0.557	28.8	28.9	43.94	41.12	39.0	38.5	25.3	25.2	+0.02	+0.0	-281	-29	-122	-25
43.8	21.1	910	0.025	+0.488	30.0	30.1	48.28	45.59	43.4	42.8	26.5	26.3	+0.02	-0.0	-313	-35	-153	-31
48.4	21.1	910	0.030	+0.418	31.1	31.4	52.61	50.05	47.9	47.2	27.7	27.5	+0.02	-0.0	-345	-41	-184	-37
52.9	21.1	910	0.035	+0.346	32.3	32.6	56.94	54.52	52.4	51.5	28.9	28.7	+0.02	-0.0	-378	-47	-217	-43
57.5	21.1	910	0.040	+0.273	33.6	33.8	61.26	58.98	56.8	55.8	30.1	29.9	+0.03	-0.0	-412	-53	-250	-49
62.1	21.1	910	0.045	+0.199	34.8	35.1	65.58	63.44	61.3	60.1	31.4	31.1	+0.03	-0.0	-446	-59	-283	-55
66.6	21.1	910	0.050	+0.123	36.1	36.4	69.90	67.89	65.8	64.5	32.7	32.3	+0.03	-0.0	-481	-64	-317	-61
71.2	21.1	910	0.055	+0.046	37.3	37.7	74.21	72.35	70.2	68.8	34.0	33.6	+0.03	-0.0	-517	-70	-352	-67

RUN
COAXDATA

PRINT GRASHOF AND NUSSELT NUMBERS, OR LOSSES (N/L)? N

NOTES: I=GLOBAL INSOLATION, [W/m2].
X=FLUID PARAMETER, (Tfluid-Tamb)/I, [DegC/(W/m2)].
EFF=(I-Qlosses)/I.

Tfluid	Tamb	I	X	EFF	Tco	Tci	Tabs1	Tabs2	Tabs3	Tabs4	Tbin	Tbout	HEAT BALANCE Front	Back	GRASHOF AND NUSSELT NUMBERS Grf	Nuf	Grb	Nub
DegC	DegC	W/m2			DegC	DegC	DegC	DegC	DegC	DegC	DegC	DegC	W/m2	W/m2				
12.0	21.1	910	-.010	+0.947	22.2	22.2	17.84	14.29	12.1	12.4	18.6	18.7	+0.01	+0.7	166	1.0	260	1.0
16.5	21.1	910	-.005	+0.885	23.3	23.3	22.20	18.77	16.6	16.7	19.7	19.7	+0.01	+0.4	39	1.0	118	1.0
21.1	21.1	910	0.000	+0.822	24.3	24.4	26.56	23.24	21.1	21.1	20.8	20.8	+0.01	-0.1	78	1.0	11	1.0
25.6	21.1	910	0.005	+0.758	25.4	25.5	30.91	27.71	25.6	25.4	21.9	21.9	+0.01	-0.8	183	1.0	127	1.0
30.2	21.1	910	0.010	+0.692	26.5	26.6	35.26	32.19	30.0	29.8	23.0	23.0	+0.01	-0.0	280	1.0	235	1.0
34.7	21.1	910	0.015	+0.625	27.7	27.8	39.60	36.65	34.5	34.1	24.2	24.1	+0.02	-0.0	367	1.0	332	1.0
39.3	21.1	910	0.020	+0.557	28.8	28.9	43.94	41.12	39.0	38.5	25.3	25.2	+0.02	+0.0	446	1.0	419	1.0
43.8	21.1	910	0.025	+0.488	30.0	30.1	48.28	45.59	43.4	42.8	26.5	26.3	+0.02	-0.0	518	1.0	499	1.0
48.4	21.1	910	0.030	+0.418	31.1	31.4	52.61	50.05	47.9	47.2	27.7	27.5	+0.02	-0.0	583	1.0	571	1.0
52.9	21.1	910	0.035	+0.346	32.3	32.6	56.94	54.52	52.4	51.5	28.9	28.7	+0.02	-0.0	642	1.0	636	1.0
57.5	21.1	910	0.040	+0.273	33.6	33.8	61.26	58.98	56.8	55.8	30.1	29.9	+0.03	-0.0	695	1.0	695	1.0
62.1	21.1	910	0.045	+0.199	34.8	35.1	65.58	63.44	61.3	60.1	31.4	31.1	+0.03	-0.0	743	1.0	748	1.0
66.6	21.1	910	0.050	+0.123	36.1	36.4	69.90	67.89	65.8	64.5	32.7	32.3	+0.03	-0.0	786	1.0	795	1.0
71.2	21.1	910	0.055	+0.046	37.3	37.7	74.21	72.35	70.2	68.8	34.0	33.6	+0.03	-0.0	824	1.0	837	1.0

COLLECTOR AND ENVIRONMENTAL FACTORS:

```
INSOLATION NORMAL TO COLLECTOR (W/SQ M)= 910
AMBIENT AIR TEMPERATURE (DEG C)= 21.1
COLLECTOR TILT ANGLE (DEG)= 45
EFFECTIVE SKY EMISSIVITY (f(Dew Pt))= .855
WIND SPEED (M/SEC)= 4.47

EMISSIVITY OF COVER= .88
TRANSMITTANCE OF COVER= .92
ABSORPTANCE OF COVER= .08
REFLECTANCE OF COVER= 0
CONDUCTIVITY OF COVER (W/M/DEG K)= .203
THICKNESS OF COVER (MM)= .203

RIB HEIGHT (DISTANCE BETWEEN 'COVER' AND ABSORBER), (cm) = .635
RADIANT TRANSFER VIEW FACTOR (ABSORBER TO COVER)= .6

ABSORBER TUBE O.D. (mm)= 6.35
ABSORBER SKIN THICKNESS (MM)= .718
CONDUCTIVITY OF ABSORBER SKIN (W/M/DEG K)= .1759
ABSORBER EMISSIVITY= .92
ABSORBER ABSORPTIVITY= .92


THICKNESS OF BACKING #1 (AIR WITH RIBS), (cm) = .635



THICKNESS OF BACKING #2 (PLASTIC), (mm) = .203
CONDUCTIVITY OF BACKING #2 (W/M/DEG K)= .203
EMISSIVITY OF BACKING #2 = .88
ABSORPTIVITY OF BACKING #2= .88
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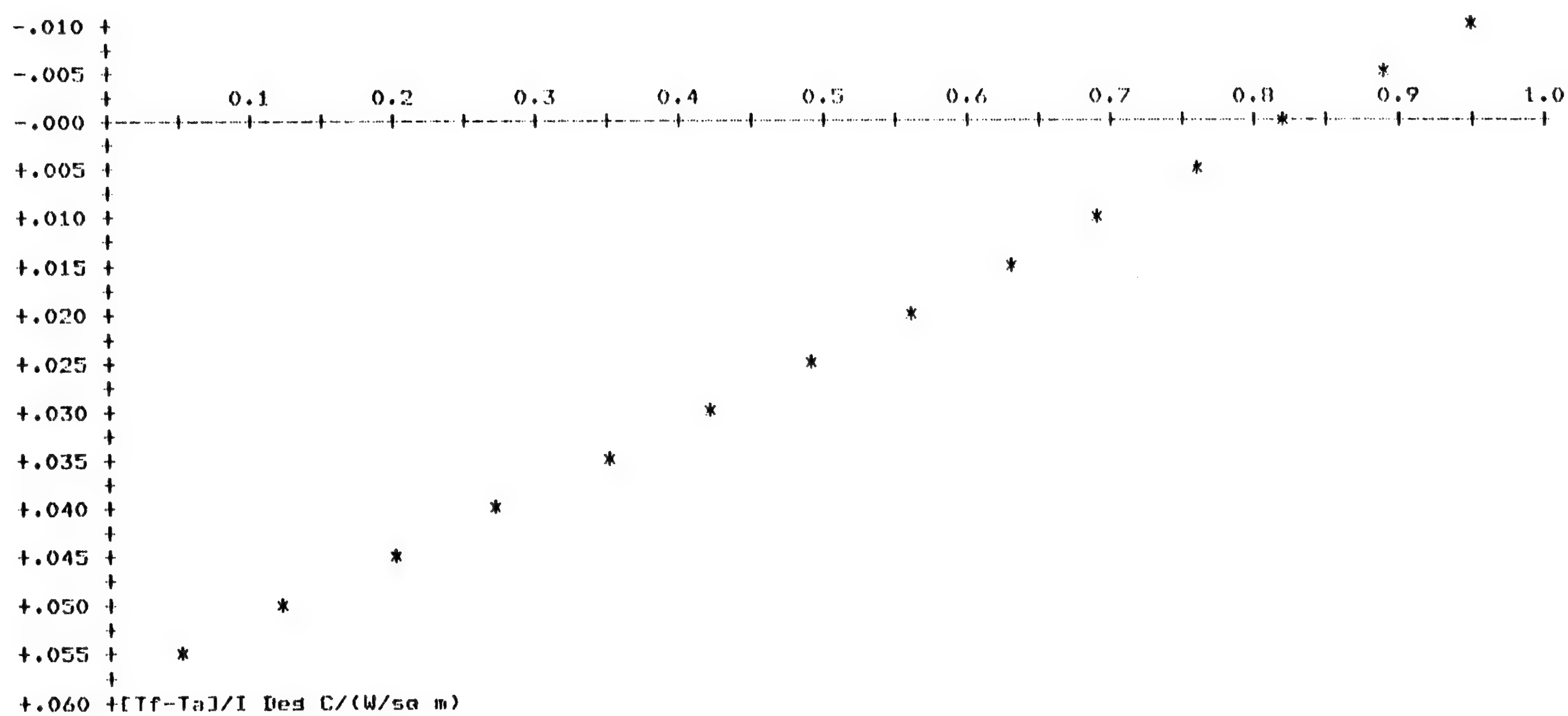
COLLECTOR EFFICIENCY



EFFICIENCY=0 AT Xo= .059 (Deg C)/(W/sq m)
Tstall = Tamb+1000*Xo =Tamb+ 58.6 DEGREES C.

CASE 9

Efficiency Comparison

Plastic VS. Copper

As Absorber Material

Based on Case 6

NOTES: I=GLOBAL INSOLATION, [W/m2].
X=FLUID PARAMETER, (Tfluid-Tamb)/I, [DegC/(W/m2)].
EFF=(I-Qlosses)/I.

													HEAT BALANCE		FRONT AND BACK LOSSES			
Tfluid DegC	Tamb DegC	I W/m2	X	EFF	Tco DegC	Tci DegC	Tabs1 DegC	Tabs2 DegC	Tabs3 DegC	Tabs4 DegC	Tbin DegC	Tbout DegC	Front W/m2	Back W/m2	Qfront W/m2	Qribf W/m2	Qback W/m2	Qribb W/m2
28.4	37.5	913	-.010	+0.916	38.3	38.3	30.73	30.73	28.4	28.4	29.4	35.5	+0.03	+0.5	-83	7	6	0
32.9	37.5	913	-.005	+0.891	40.2	40.2	35.24	35.24	32.9	32.9	33.3	35.9	+0.03	+0.2	-102	5	3	0
37.5	37.5	913	0.000	+0.866	42.1	42.1	39.75	39.75	37.5	37.5	37.3	36.3	+0.03	-0.4	-122	2	-1	-0
42.1	37.5	913	0.005	+0.839	44.1	44.1	44.26	44.26	42.0	42.0	41.3	36.7	+0.03	+0.0	-142	-0	-5	-0
46.6	37.5	913	0.010	+0.813	46.0	46.1	48.77	48.77	46.6	46.6	45.4	37.1	+0.03	-0.0	-162	-3	-9	-0
51.2	37.5	913	0.015	+0.785	48.0	48.1	53.28	53.28	51.2	51.2	49.4	37.5	+0.03	-0.0	-183	-5	-13	-0
55.8	37.5	913	0.020	+0.757	50.1	50.1	57.78	57.78	55.7	55.7	53.5	37.8	+0.03	-0.0	-205	-8	-17	-0
60.3	37.5	913	0.025	+0.729	52.1	52.2	62.29	62.29	60.3	60.3	57.6	38.2	+0.03	-0.0	-227	-10	-21	-0
64.9	37.5	913	0.030	+0.700	54.2	54.2	66.79	66.79	64.8	64.8	61.7	38.6	+0.03	-0.0	-249	-12	-25	-0
69.4	37.5	913	0.035	+0.670	56.3	56.4	71.29	71.29	69.4	69.4	65.9	39.0	+0.03	-0.0	-272	-15	-29	-0
74.0	37.5	913	0.040	+0.640	58.4	58.5	75.80	75.79	73.9	73.9	70.0	39.4	+0.03	-0.0	-296	-17	-33	-1
78.6	37.5	913	0.045	+0.609	60.5	60.6	80.29	80.29	78.5	78.5	74.2	39.8	+0.03	-0.0	-320	-19	-37	-1
83.1	37.5	913	0.050	+0.577	62.7	62.8	84.79	84.79	83.0	83.0	78.4	40.2	+0.03	-0.0	-345	-22	-41	-1
87.7	37.5	913	0.055	+0.545	64.9	65.0	89.29	89.29	87.6	87.6	82.6	40.6	+0.03	-0.1	-371	-24	-45	-1
92.3	37.5	913	0.060	+0.512	67.1	67.3	93.78	93.78	92.1	92.1	86.9	41.0	+0.03	-0.1	-397	-26	-49	-1
96.8	37.5	913	0.065	+0.478	69.3	69.5	98.27	98.27	96.7	96.7	91.1	41.4	+0.03	-0.1	-423	-28	-53	-1
101.4	37.5	913	0.070	+0.444	71.6	71.8	102.77	102.76	101.2	101.2	95.4	41.9	+0.03	-0.1	-450	-30	-57	-1
105.9	37.5	913	0.075	+0.409	73.9	74.1	107.25	107.25	105.8	105.8	99.7	42.3	+0.03	-0.2	-478	-33	-61	-1
110.5	37.5	913	0.080	+0.373	76.2	76.4	111.74	111.74	110.3	110.3	104.0	42.7	-0.09	-0.2	-507	-35	-65	-1
115.1	37.5	913	0.085	+0.336	78.5	78.8	116.23	116.23	114.9	114.9	108.3	43.1	-0.14	-0.2	-536	-37	-70	-1
119.6	37.5	913	0.090	+0.298	80.9	81.2	120.71	120.71	119.4	119.4	112.6	43.5	-0.04	-0.3	-567	-39	-74	-1
124.2	37.5	913	0.095	+0.260	83.3	83.6	125.19	125.19	124.0	124.0	116.9	43.9	+0.02	-0.4	-597	-41	-78	-1
128.8	37.5	913	0.100	+0.221	85.7	86.0	129.67	129.67	128.5	128.5	121.3	44.3	+0.02	-0.4	-629	-43	-82	-1
133.3	37.5	913	0.105	+0.181	88.1	88.4	134.15	134.15	133.1	133.1	125.6	44.7	+0.01	-0.5	-661	-45	-87	-1
137.9	37.5	913	0.110	+0.140	90.6	90.9	138.63	138.63	137.6	137.6	130.0	45.1	+0.01	-0.6	-694	-47	-91	-1
142.4	37.5	913	0.115	+0.098	93.0	93.4	143.10	143.10	142.2	142.2	134.4	45.5	+0.00	-0.7	-728	-49	-95	-1
147.0	37.5	913	0.120	+0.056	95.5	95.9	147.57	147.57	146.8	146.8	138.8	46.0	-0.00	-0.8	-762	-51	-100	-1

NOTES: I=GLOBAL INSOLATION, [W/m2].
X=FLUID PARAMETER, (Tfluid-Tamb)/I, [DegC/(W/m2)].
EFF=(I-Qlosses)/I.

Tfluid DegC	Tamb DegC	I W/m2	X	EFF	Tco DegC	Tci DegC	Tabs1 DegC	Tabs2 DegC	Tabs3 DegC	Tabs4 DegC	Tbin DegC	Tbout DegC	HEAT BALANCE Front W/m2	Back W/m2	GRASHOF AND NUSSELT NUMBERS Grf	Nuf	Grb	Nub
28.4	37.5	913	-.010	+0.916	38.3	38.3	30.73	30.73	28.4	28.4	29.4	35.5	+0.03	+0.5	452	1.0	64	1.0
32.9	37.5	913	-.005	+0.891	40.2	40.2	35.24	35.24	32.9	32.9	33.3	35.9	+0.03	+0.2	282	1.0	25	1.0
37.5	37.5	913	0.000	+0.866	42.1	42.1	39.75	39.75	37.5	37.5	37.3	36.3	+0.03	-0.4	129	1.0	9	1.0
42.1	37.5	913	0.005	+0.839	44.1	44.1	44.26	44.26	42.0	42.0	41.3	36.7	+0.03	+0.0	10	1.0	38	1.0
46.6	37.5	913	0.010	+0.813	46.0	46.1	48.77	48.77	46.6	46.6	45.4	37.1	+0.03	-0.0	135	1.0	62	1.0
51.2	37.5	913	0.015	+0.785	48.0	48.1	53.28	53.28	51.2	51.2	49.4	37.5	+0.03	-0.0	247	1.0	82	1.0
55.8	37.5	913	0.020	+0.757	50.1	50.1	57.78	57.78	55.7	55.7	53.5	37.8	+0.03	-0.0	349	1.0	99	1.0
60.3	37.5	913	0.025	+0.729	52.1	52.2	62.29	62.29	60.3	60.3	57.6	38.2	+0.03	-0.0	440	1.0	112	1.0
64.9	37.5	913	0.030	+0.700	54.2	54.2	66.79	66.79	64.8	64.8	61.7	38.6	+0.03	-0.0	521	1.0	123	1.0
69.4	37.5	913	0.035	+0.670	56.3	56.4	71.29	71.29	69.4	69.4	65.9	39.0	+0.03	-0.0	594	1.0	132	1.0
74.0	37.5	913	0.040	+0.640	58.4	58.5	75.80	75.79	73.9	73.9	70.0	39.4	+0.03	-0.0	659	1.0	139	1.0
78.6	37.5	913	0.045	+0.609	60.5	60.6	80.29	80.29	78.5	78.5	74.2	39.8	+0.03	-0.0	718	1.0	144	1.0
83.1	37.5	913	0.050	+0.577	62.7	62.8	84.79	84.79	83.0	83.0	78.4	40.2	+0.03	-0.0	769	1.0	148	1.0
87.7	37.5	913	0.055	+0.545	64.9	65.0	89.29	89.29	87.6	87.6	82.6	40.6	+0.03	-0.1	815	1.0	151	1.0
92.3	37.5	913	0.060	+0.512	67.1	67.3	93.78	93.78	92.1	92.1	86.9	41.0	+0.03	-0.1	855	1.0	152	1.0
96.8	37.5	913	0.065	+0.478	69.3	69.5	98.27	98.27	96.7	96.7	91.1	41.4	+0.03	-0.1	891	1.0	153	1.0
101.4	37.5	913	0.070	+0.444	71.6	71.8	102.77	102.76	101.2	101.2	95.4	41.9	+0.03	-0.1	922	1.0	153	1.0
105.9	37.5	913	0.075	+0.409	73.9	74.1	107.25	107.25	105.8	105.8	99.7	42.3	+0.03	-0.2	948	1.0	153	1.0
110.5	37.5	913	0.080	+0.373	76.2	76.4	111.74	111.74	110.3	110.3	104.0	42.7	-0.09	-0.2	971	1.0	151	1.0
115.1	37.5	913	0.085	+0.336	78.5	78.8	116.23	116.23	114.9	114.9	108.3	43.1	-0.14	-0.2	990	1.0	150	1.0
119.6	37.5	913	0.090	+0.298	80.9	81.2	120.71	120.71	119.4	119.4	112.6	43.5	-0.04	-0.3	1006	1.0	148	1.0
124.2	37.5	913	0.095	+0.260	83.3	83.6	125.19	125.19	124.0	124.0	116.9	43.9	+0.02	-0.4	1020	1.0	146	1.0
128.8	37.5	913	0.100	+0.221	85.7	86.0	129.67	129.67	128.5	128.5	121.3	44.3	+0.02	-0.4	1030	1.0	143	1.0
133.3	37.5	913	0.105	+0.181	88.1	88.4	134.15	134.15	133.1	133.1	125.6	44.7	+0.01	-0.5	1039	1.0	140	1.0
137.9	37.5	913	0.110	+0.140	90.6	90.9	138.63	138.63	137.6	137.6	130.0	45.1	+0.01	-0.6	1045	1.0	138	1.0
142.4	37.5	913	0.115	+0.098	93.0	93.4	143.10	143.10	142.2	142.2	134.4	45.5	+0.00	-0.7	1050	1.0	135	1.0
147.0	37.5	913	0.120	+0.056	95.5	95.9	147.57	147.57	146.8	146.8	138.8	46.0	-0.00	-0.8	1052	1.0	131	1.0

COLLECTOR AND ENVIRONMENTAL FACTORS:

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INSOLATION NORMAL TO COLLECTOR (W/SQ M)= 912.6
AMBIENT AIR TEMPERATURE (DEG C)= 37.5
COLLECTOR TILT ANGLE (DEG)= 45
EFFECTIVE SKY EMISSIVITY (f(Dew Pt))= .855
WIND SPEED (M/SEC)= .2

EMISSIVITY OF COVER= .88
TRANSMITTANCE OF COVER= .92
ABSORPTANCE OF COVER= .08
REFLECTANCE OF COVER= 0
CONDUCTIVITY OF COVER (W/M/DEG K)= .203
THICKNESS OF COVER (MM)= .127

RIB HEIGHT (DISTANCE BETWEEN 'COVER' AND ABSORBER), (cm) = .794
RADIANT TRANSFER VIEW FACTOR (ABSORBER TO COVER)= .6

ABSORBER TUBE O.D. (mm)= 6.35
ABSORBER SKIN THICKNESS (MM)= .718
CONDUCTIVITY OF ABSORBER SKIN (W/M/DEG K)= 385
ABSORBER EMISSIVITY= .92
ABSORBER ABSORPTIVITY= .92

THICKNESS OF BACKING #1 (AIR WITH RIBS), (cm) = .794

THICKNESS OF BACKING #2 (PLASTIC), (mm) = 25.4
CONDUCTIVITY OF BACKING #2 (W/M/DEG K)= .027
EMISSIVITY OF BACKING #2 = .88
ABSORPTIVITY OF BACKING #2= .88
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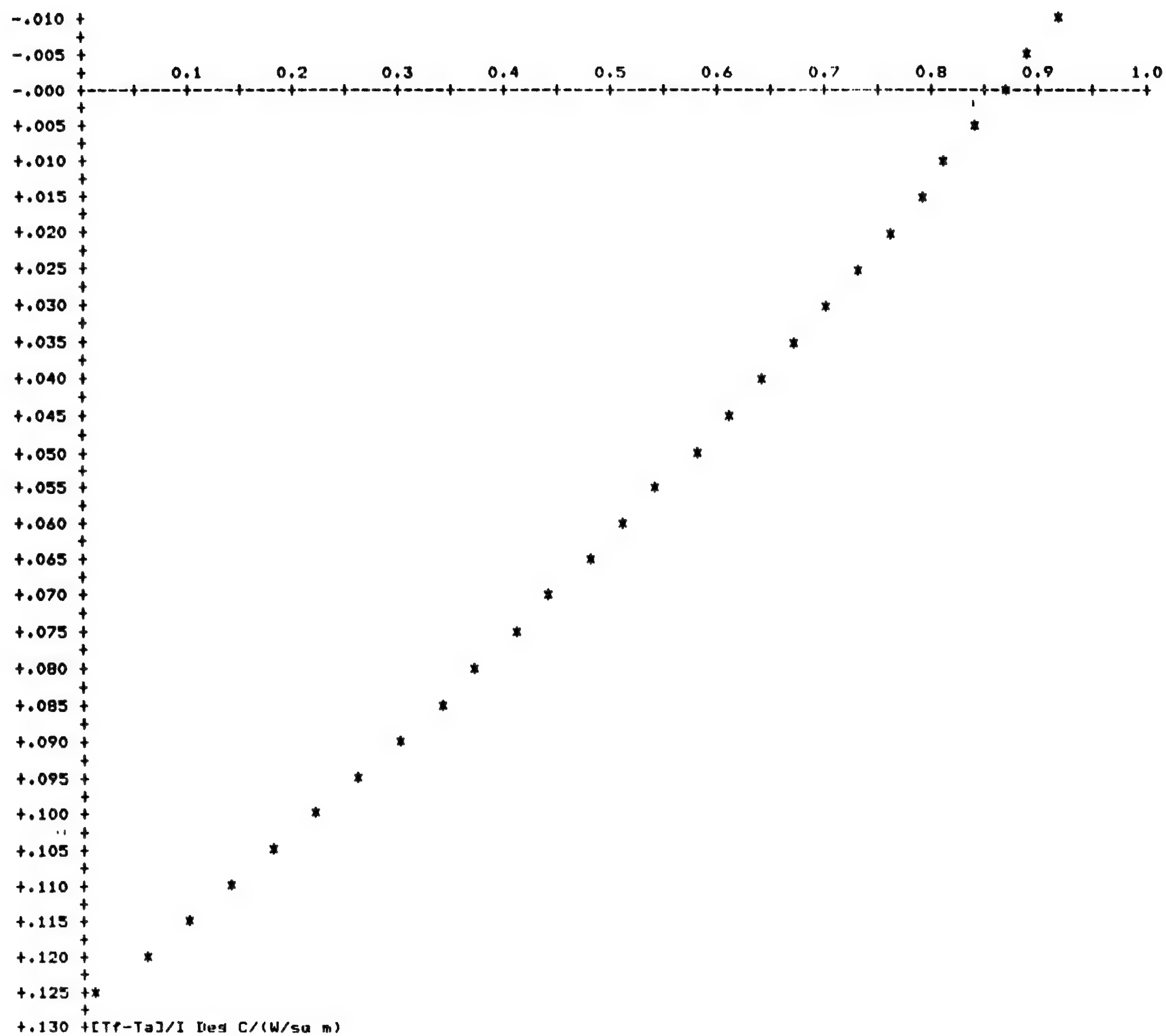


EFFICIENCY=0 AT Xo= .126 (Deg C)/(W/sq m)
Tstall = Tamb+1000*Xo =Tamb+126.0 DEGREES C.

CASE 10

22.2 mm Height

Air Backing

0.5 m/s Wind Velocity

NOTES: I=GLOBAL INSOLATION, [W/m2].
X=FLUID PARAMETER, (Tfluid-Tamb)/I, [DegC/(W/m2)].
EFF=(I-Qlosses)/I.

Tfluid	Tamb	I	X	EFF	Tco	Tci	Tabs1	Tabs2	Tabs3	Tabs4	Tbin	Tbout	HEAT BALANCE		FRONT AND BACK LOSSES			
DegC	DegC	W/m2			DegC	DegC	DegC	DegC	DegC	DegC	DegC	DegC	Front W/m2	Back W/m2	Qfront W/m2	Qribf W/m2	Qback W/m2	Qribb W/m2
31.6	39.8	816	-.010	+0.928	41.6	41.6	36.90	33.71	31.7	31.8	35.9	35.9	-0.06	+0.1	-89	5	30	4
35.7	39.8	816	-.005	+0.884	43.2	43.2	40.85	37.74	35.8	35.8	37.5	37.5	-0.06	-0.1	-107	2	13	2
39.8	39.8	816	0.000	+0.839	44.8	44.8	44.81	41.77	39.8	39.8	39.1	39.1	-0.06	-0.4	-126	-0	-5	-1
43.9	39.8	816	0.005	+0.794	46.4	46.4	48.76	45.79	43.8	43.7	40.7	40.7	-0.05	-0.6	-145	-2	-23	-3
48.0	39.8	816	0.010	+0.747	48.0	48.0	52.71	49.82	47.8	47.7	42.4	42.4	-0.05	-0.9	-164	-5	-42	-5
52.0	39.8	816	0.015	+0.699	49.7	49.7	56.66	53.85	51.9	51.6	44.0	44.0	-0.05	-0.0	-184	-7	-62	-7
56.1	39.8	816	0.020	+0.651	51.3	51.4	60.60	57.87	55.9	55.6	45.7	45.7	-0.04	+0.0	-204	-9	-81	-10
60.2	39.8	816	0.025	+0.602	53.0	53.1	64.54	61.90	59.9	59.5	47.5	47.4	-0.04	-0.0	-224	-11	-101	-12
64.3	39.8	816	0.030	+0.551	54.7	54.8	68.48	65.92	64.0	63.5	49.2	49.1	-0.03	-0.0	-245	-13	-121	-14
68.3	39.8	816	0.035	+0.500	56.5	56.5	72.41	69.95	68.0	67.4	50.9	50.8	-0.03	-0.0	-266	-16	-142	-16
72.4	39.8	816	0.040	+0.447	58.2	58.3	76.35	73.97	72.0	71.3	52.7	52.6	-0.02	+0.0	-288	-18	-163	-18
76.5	39.8	816	0.045	+0.393	60.0	60.1	80.28	77.99	76.0	75.3	54.5	54.3	-0.02	+0.0	-310	-20	-185	-20
80.6	39.8	816	0.050	+0.339	61.8	61.9	84.20	82.01	80.0	79.2	56.3	56.1	-0.01	-0.0	-333	-22	-207	-22
84.7	39.8	816	0.055	+0.283	63.6	63.7	88.13	86.02	84.1	83.1	58.1	57.9	-0.01	-0.0	-356	-24	-229	-25
88.7	39.8	816	0.060	+0.226	65.4	65.5	92.05	90.04	88.1	87.0	60.0	59.7	-0.00	-0.0	-379	-26	-252	-27
92.8	39.8	816	0.065	+0.168	67.2	67.4	95.96	94.05	92.1	91.0	61.9	61.6	+0.01	+0.0	-403	-28	-275	-29
96.9	39.8	816	0.070	+0.109	69.1	69.3	99.88	98.07	96.1	94.9	63.7	63.4	-0.02	+0.0	-428	-30	-299	-31
101.0	39.8	816	0.075	+0.049	71.0	71.2	103.79	102.08	100.1	98.8	65.6	65.3	-0.11	+0.0	-453	-32	-323	-33

NOTES: I=GLOBAL INSOLATION, [W/m2].
X=FLUID PARAMETER, (Tfluid-Tamb)/I, [DegC/(W/m2)].
EFF=(I-Qlosses)/I.

Tfluid DegC	Tamb DegC	I W/m2	X	EFF	Tco DegC	Tci DegC	Tabs1 DegC	Tabs2 DegC	Tabs3 DegC	Tabs4 DegC	Tbin DegC	Tbout DegC	HEAT BALANCE Front W/m2	Back W/m2	GRASHOF AND NUSSELT NUMBERS Grf	Nuf	Grb	Nub
31.6	39.8	816	-.010	+0.928	41.6	41.6	36.90	33.71	31.7	31.8	35.9	35.9	-0.06	+0.1	261	1.0	243	1.0
35.7	39.8	816	-.005	+0.884	43.2	43.2	40.85	37.74	35.8	35.8	37.5	37.5	-0.06	-0.1	123	1.0	96	1.0
39.8	39.8	816	0.000	+0.839	44.8	44.8	44.81	41.77	39.8	39.8	39.1	39.1	-0.06	-0.4	3	1.0	37	1.0
43.9	39.8	816	0.005	+0.794	46.4	46.4	48.76	45.79	43.8	43.7	40.7	40.7	-0.05	-0.6	118	1.0	159	1.0
48.0	39.8	816	0.010	+0.747	48.0	48.0	52.71	49.82	47.8	47.7	42.4	42.4	-0.05	-0.9	223	1.0	270	1.0
52.0	39.8	816	0.015	+0.699	49.7	49.7	56.66	53.85	51.9	51.6	44.0	44.0	-0.05	-0.0	319	1.0	374	1.0
56.1	39.8	816	0.020	+0.651	51.3	51.4	60.60	57.87	55.9	55.6	45.7	45.7	-0.04	+0.0	407	1.0	466	1.0
60.2	39.8	816	0.025	+0.602	53.0	53.1	64.54	61.90	59.9	59.5	47.5	47.4	-0.04	-0.0	487	1.0	550	1.0
64.3	39.8	816	0.030	+0.551	54.7	54.8	68.48	65.92	64.0	63.5	49.2	49.1	-0.03	-0.0	559	1.0	627	1.0
68.3	39.8	816	0.035	+0.500	56.5	56.5	72.41	69.95	68.0	67.4	50.9	50.8	-0.03	-0.0	626	1.0	696	1.0
72.4	39.8	816	0.040	+0.447	58.2	58.3	76.35	73.97	72.0	71.3	52.7	52.6	-0.02	+0.0	686	1.0	758	1.0
76.5	39.8	816	0.045	+0.393	60.0	60.1	80.28	77.99	76.0	75.3	54.5	54.3	-0.02	+0.0	740	1.0	814	1.0
80.6	39.8	816	0.050	+0.339	61.8	61.9	84.20	82.01	80.0	79.2	56.3	56.1	-0.01	-0.0	789	1.0	865	1.0
84.7	39.8	816	0.055	+0.283	63.6	63.7	88.13	86.02	84.1	83.1	58.1	57.9	-0.01	-0.0	833	1.0	910	1.0
88.7	39.8	816	0.060	+0.226	65.4	65.5	92.05	90.04	88.1	87.0	60.0	59.7	-0.00	-0.0	873	1.0	951	1.0
92.8	39.8	816	0.065	+0.168	67.2	67.4	95.96	94.05	92.1	91.0	61.9	61.6	+0.01	+0.0	909	1.0	987	1.0
96.9	39.8	816	0.070	+0.109	69.1	69.3	99.88	98.07	96.1	94.9	63.7	63.4	-0.02	+0.0	940	1.0	1019	1.0
101.0	39.8	816	0.075	+0.049	71.0	71.2	103.79	102.08	100.1	98.8	65.6	65.3	-0.11	+0.0	969	1.0	1048	1.0

```
COLLECTOR AND ENVIRONMENTAL FACTORS:

INSOLATION NORMAL TO COLLECTOR (W/SQ M)= 815.7
AMBIENT AIR TEMPERATURE (DEG C)= 39.8
COLLECTOR TILT ANGLE (DEG)= 45
EFFECTIVE SKY EMISSIVITY (f(Dew Pt))= .855
WIND SPEED (M/SEC)= .5

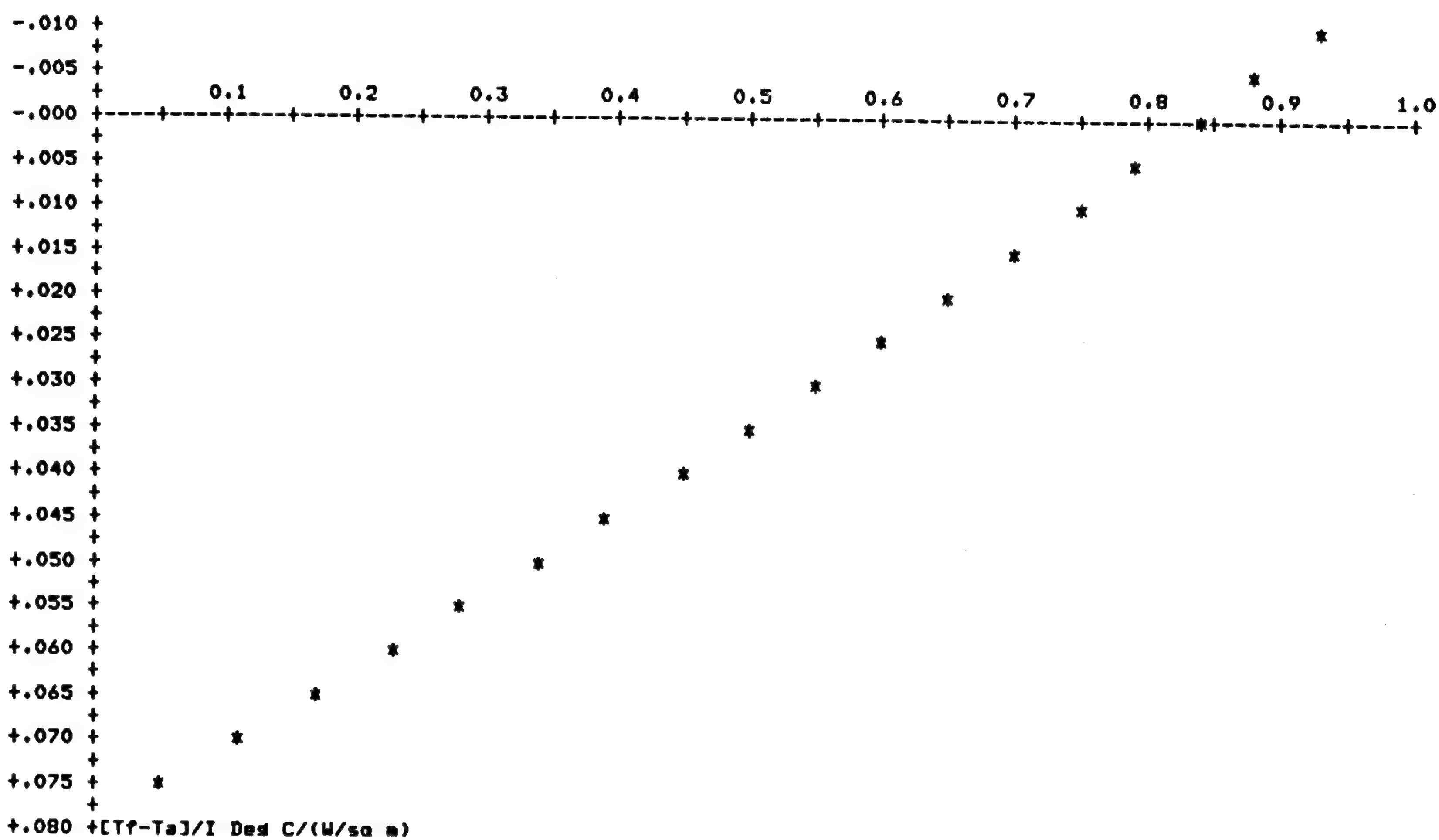
EMISSIVITY OF COVER= .88
TRANSMITTANCE OF COVER= .92
ABSORPTANCE OF COVER= .08
REFLECTANCE OF COVER= 0
CONDUCTIVITY OF COVER (W/M/DEG K)= .203
THICKNESS OF COVER (MM)= .127

RIB HEIGHT (DISTANCE BETWEEN 'COVER' AND ABSORBER), (cm) = .794
RADIANT TRANSFER VIEW FACTOR (ABSORBER TO COVER)= .6

ABSORBER TUBE O.D. (mm)= 6.35
ABSORBER SKIN THICKNESS (MM)= .718
CONDUCTIVITY OF ABSORBER SKIN (W/M/DEG K)= .1759
ABSORBER EMISSIVITY= .92
ABSORBER ABSORPTIVITY= .92

THICKNESS OF BACKING #1 (AIR WITH RIBS), (cm) = .794

THICKNESS OF BACKING #2 (PLASTIC), (mm) = .203
CONDUCTIVITY OF BACKING #2 (W/M/DEG K)= .203
EMISSIVITY OF BACKING #2 = .88
ABSORPTIVITY OF BACKING #2= .88
```



EFFICIENCY=0 AT Xo= .079 (Deg C)/(W/sq m)
Tstall = Tamb+1000*Xo =Tamb+ 79.2 DEGREES C.

MATERIALS EVALUATION

GRAPHS AND TABLES

EXHIBIT B

MATERIALS EVALUATION

GRAPHS

MATERIAL: Polycarbonate

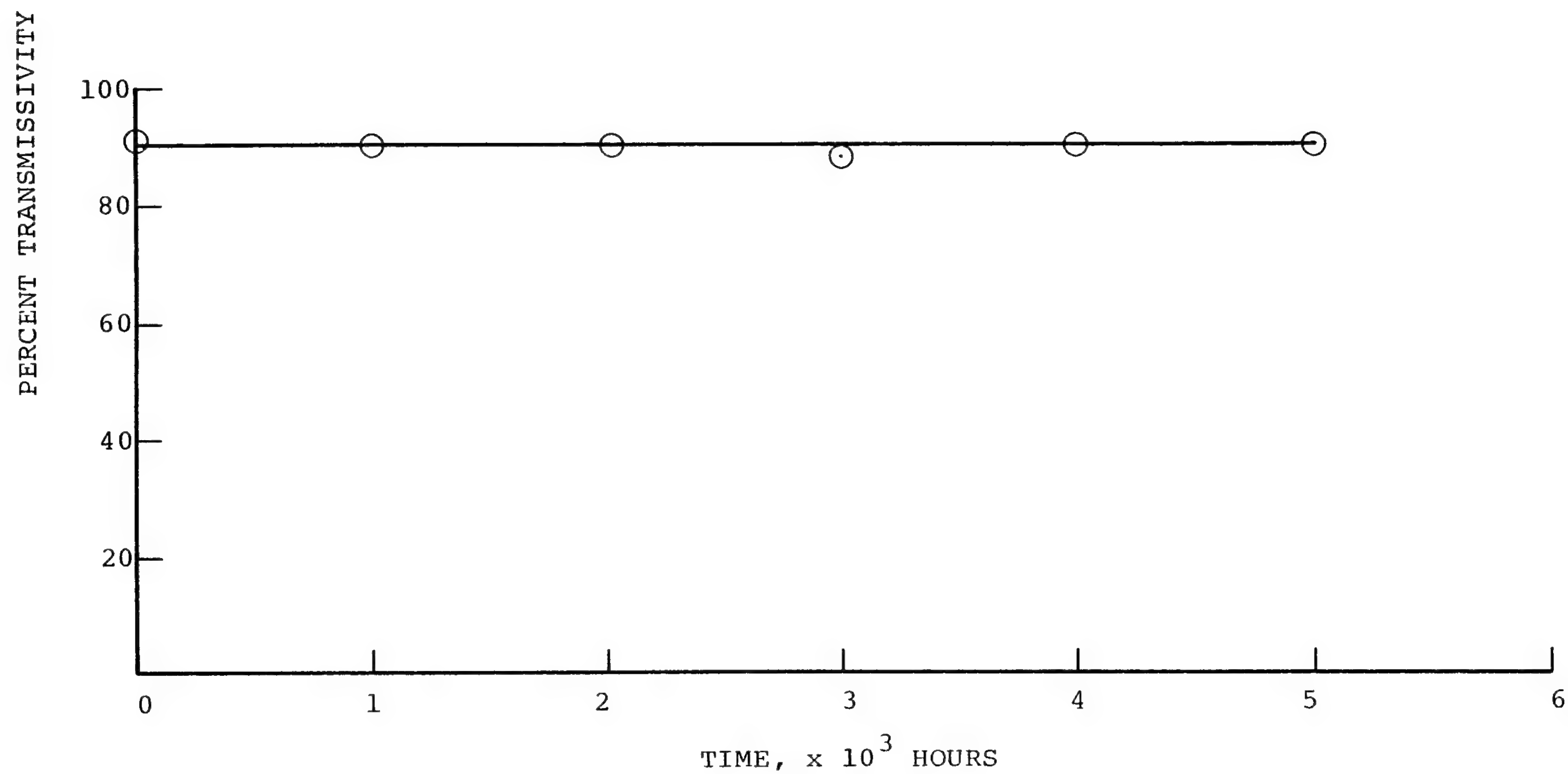
THICKNESS: 0.127 mm (5mil)

COATING: None

LAMINATED: No

ACCELERATING ENVIRONMENT: UV Aging

TRANSMISSIVITY VS. TIME



MATERIAL: Polycarbonate

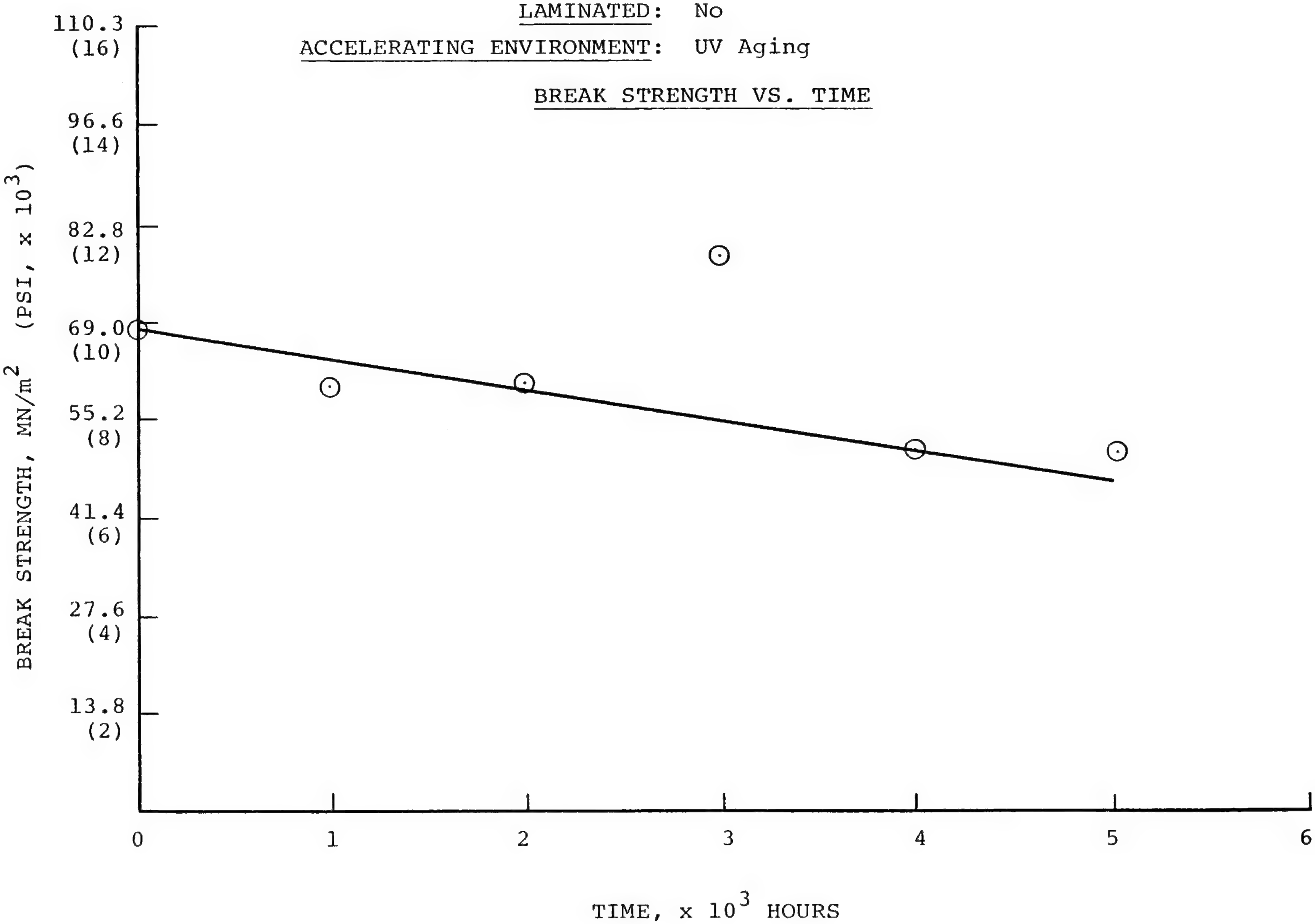
THICKNESS: 0.127 mm (5mil)

COATING: None

LAMINATED: No

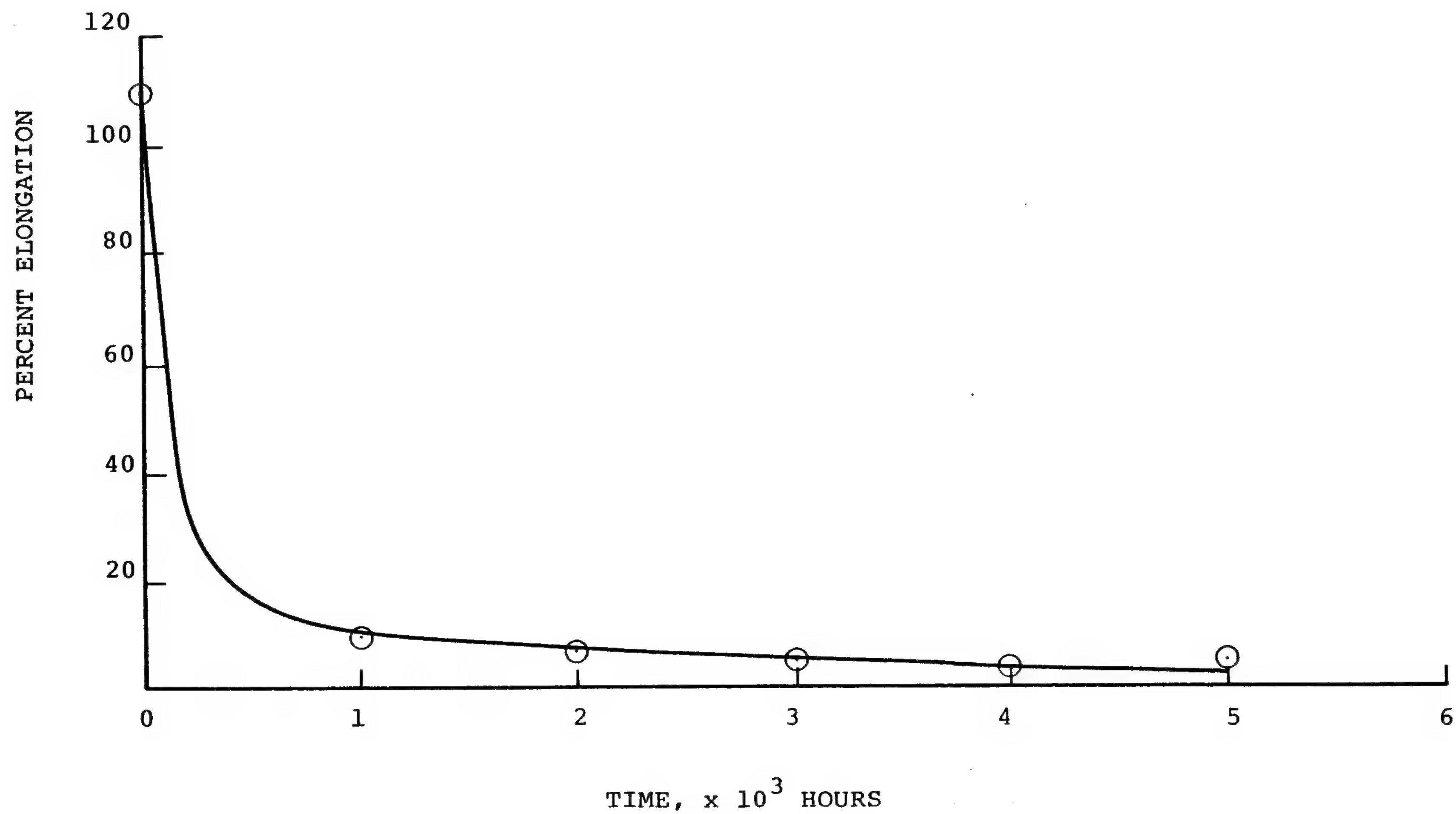
ACCELERATING ENVIRONMENT: UV Aging

BREAK STRENGTH VS. TIME



MATERIAL:	Polycarbonate
THICKNESS:	0.127 mm (5mil)
COATING:	None
LAMINATED:	No
ACCELERATING ENVIRONMENT:	UV Aging

ELONGATION VS. TIME



MATERIAL: Polycarbonate

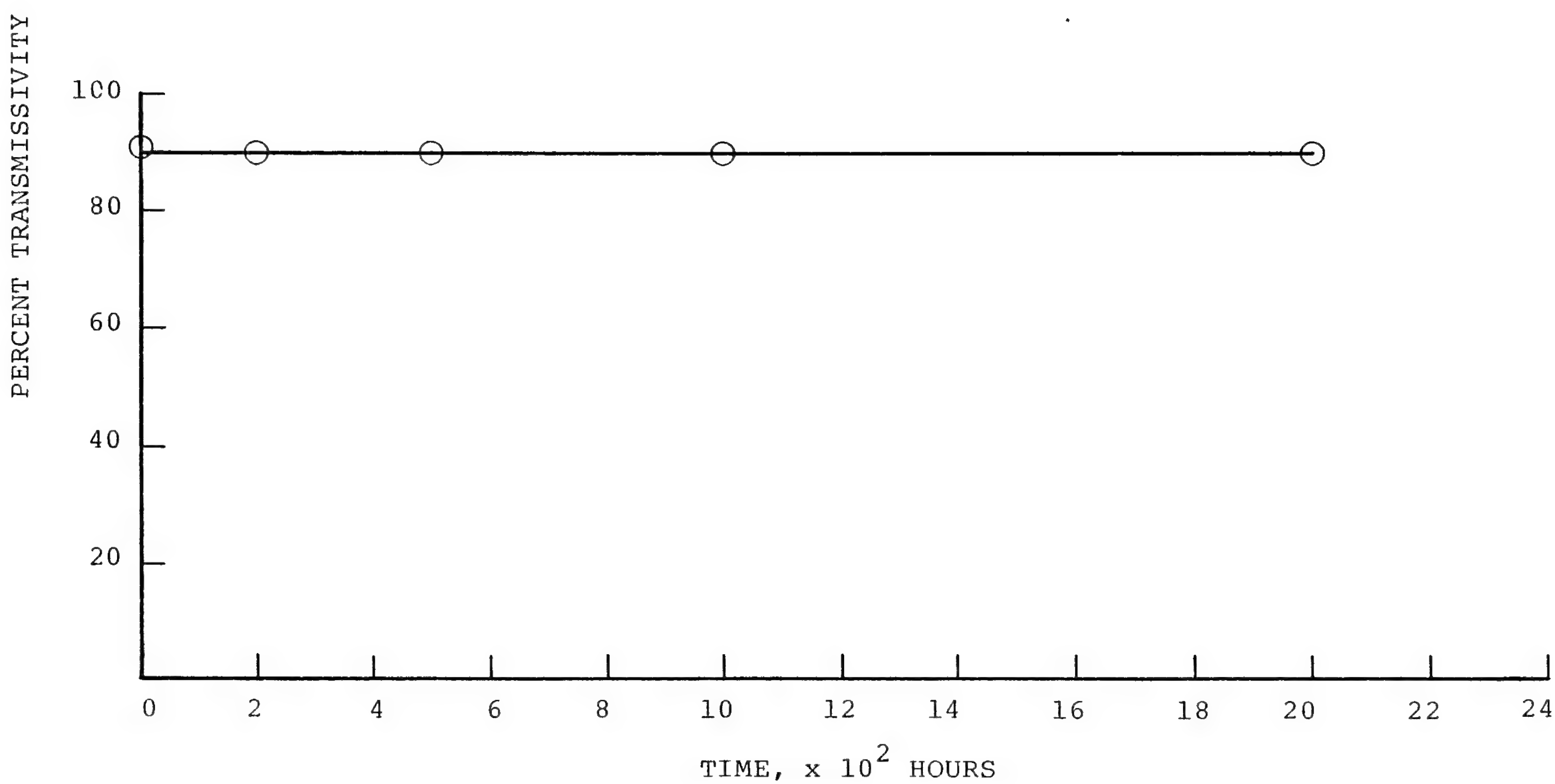
THICKNESS: 0.254 mm (10mil)

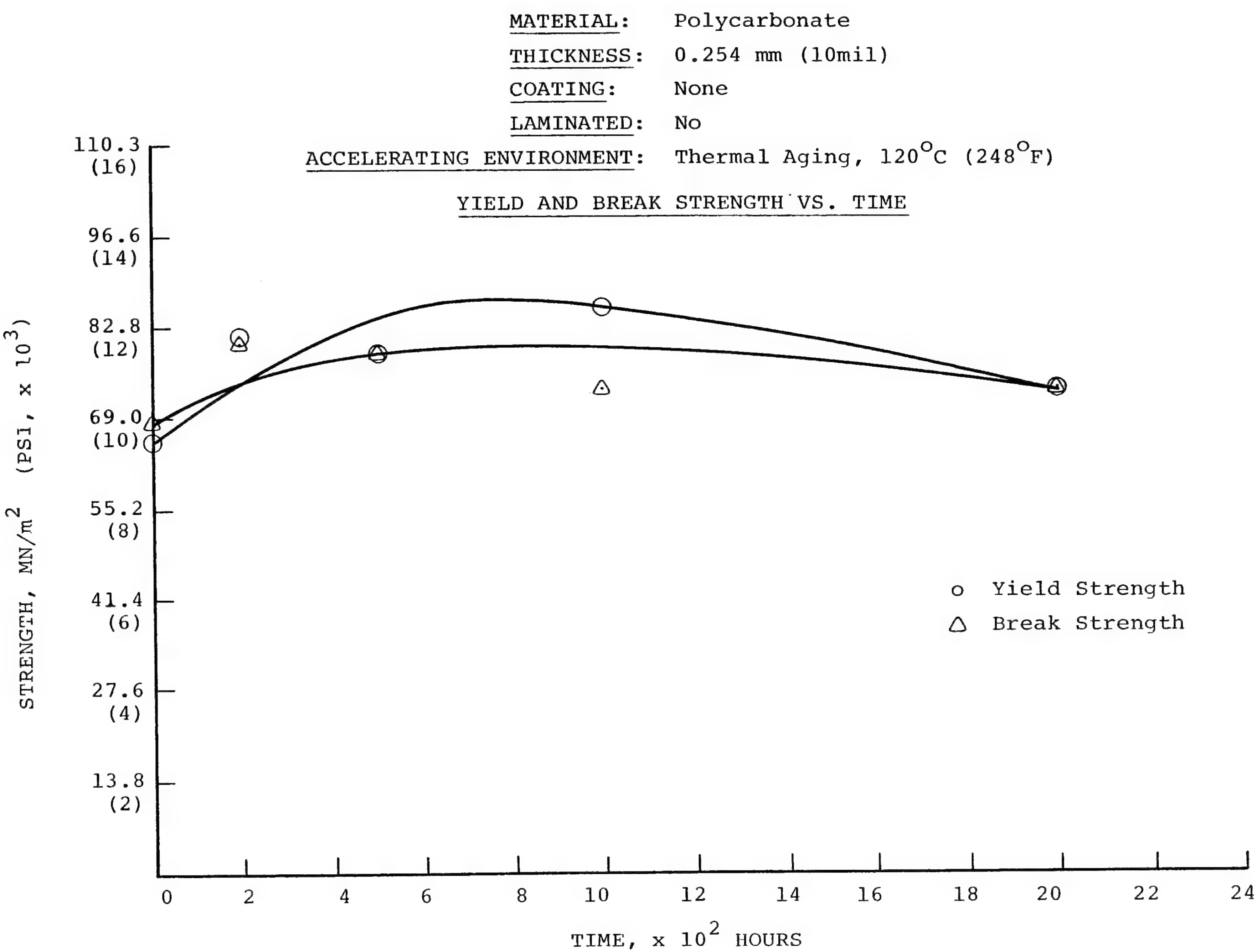
COATING: None

LAMINATED: No

ACCELERATING ENVIRONMENT: Thermal Aging, 120°C (248°F)

TRANSMISSIVITY VS. TIME

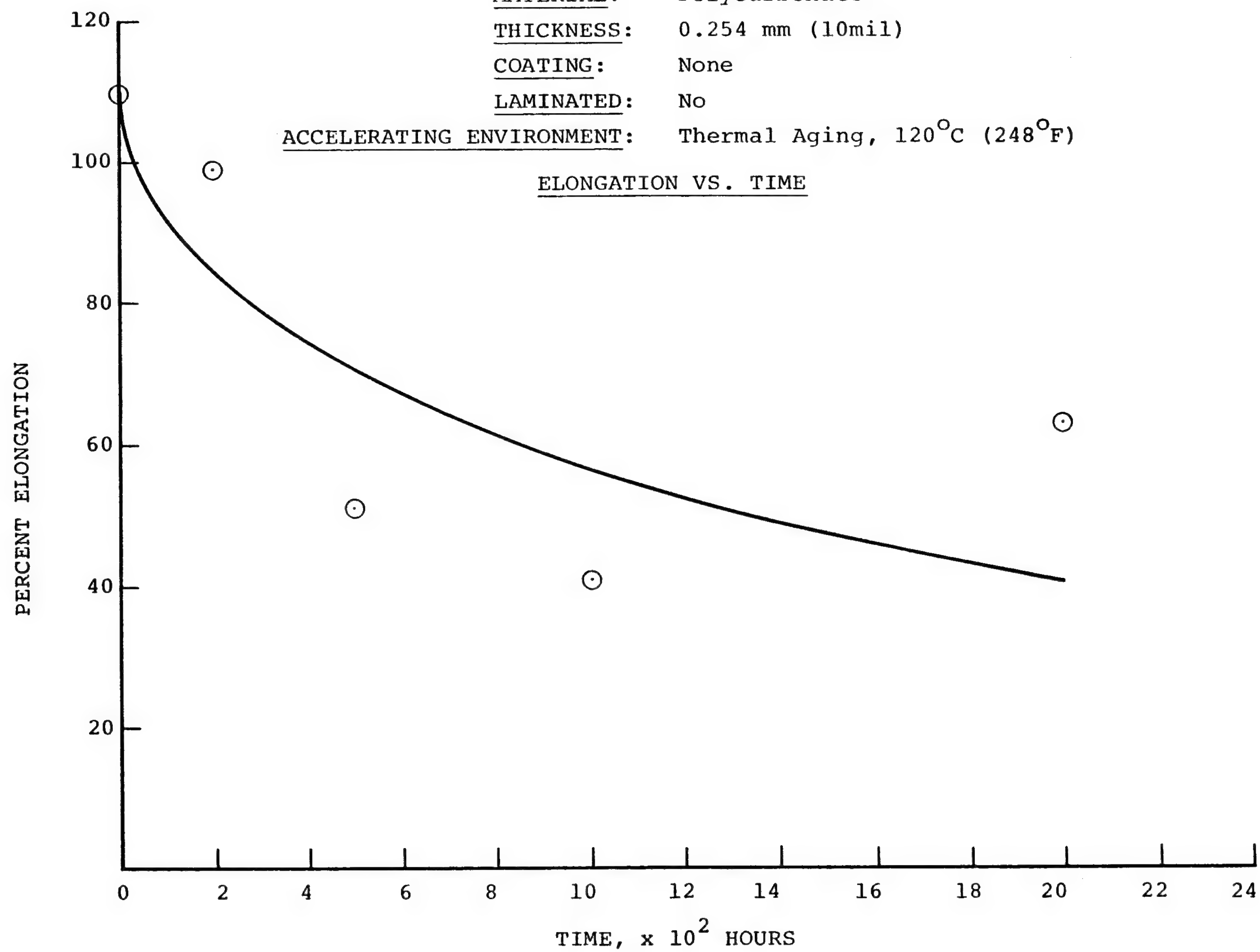




MATERIAL: Polycarbonate
THICKNESS: 0.254 mm (10mil)
COATING: None
LAMINATED: No
ACCELERATING ENVIRONMENT: Thermal Aging, 120°C (248°F)
YIELD AND BREAK STRENGTH VS. TIME
110.3 (16)
96.6 (14)
82.8 (12)
69.0 (10)
55.2 (8)
41.4 (6)
27.6 (4)
13.8 (2)
STRENGTH, MN/m2 (PSI, x 10³)
0
2
4
6
8
10
12
14
16
18
20
22
24
TIME, x 10² HOURS
o Yield Strength
△ Break Strength

MATERIAL: Polycarbonate
THICKNESS: 0.254 mm (10mil)
COATING: None
LAMINATED: No
ACCELERATING ENVIRONMENT: Thermal Aging, 120°C (248°F)

ELONGATION VS. TIME



MATERIAL: Polycarbonate

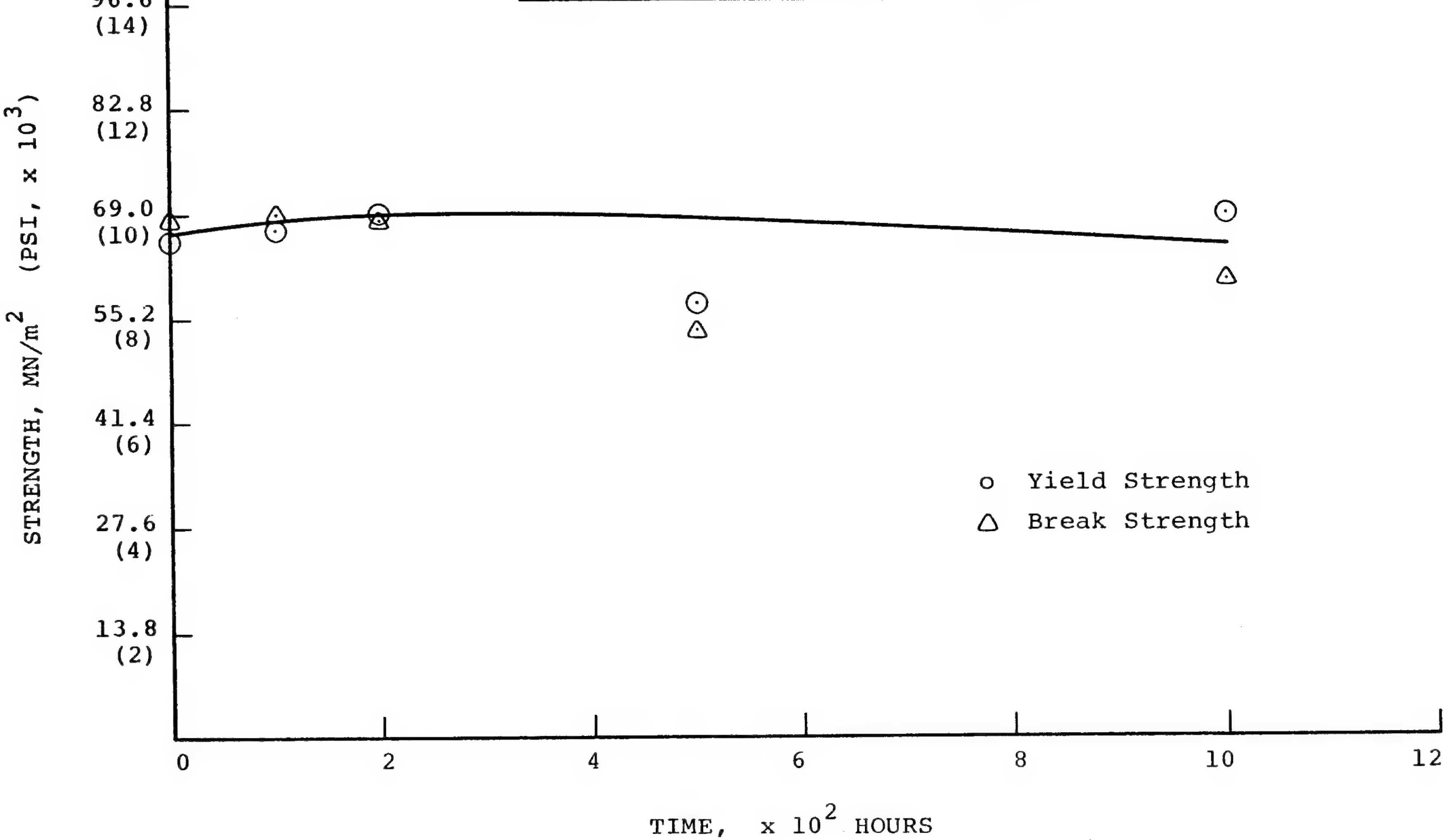
THICKNESS: 0.254 mm (10mil)

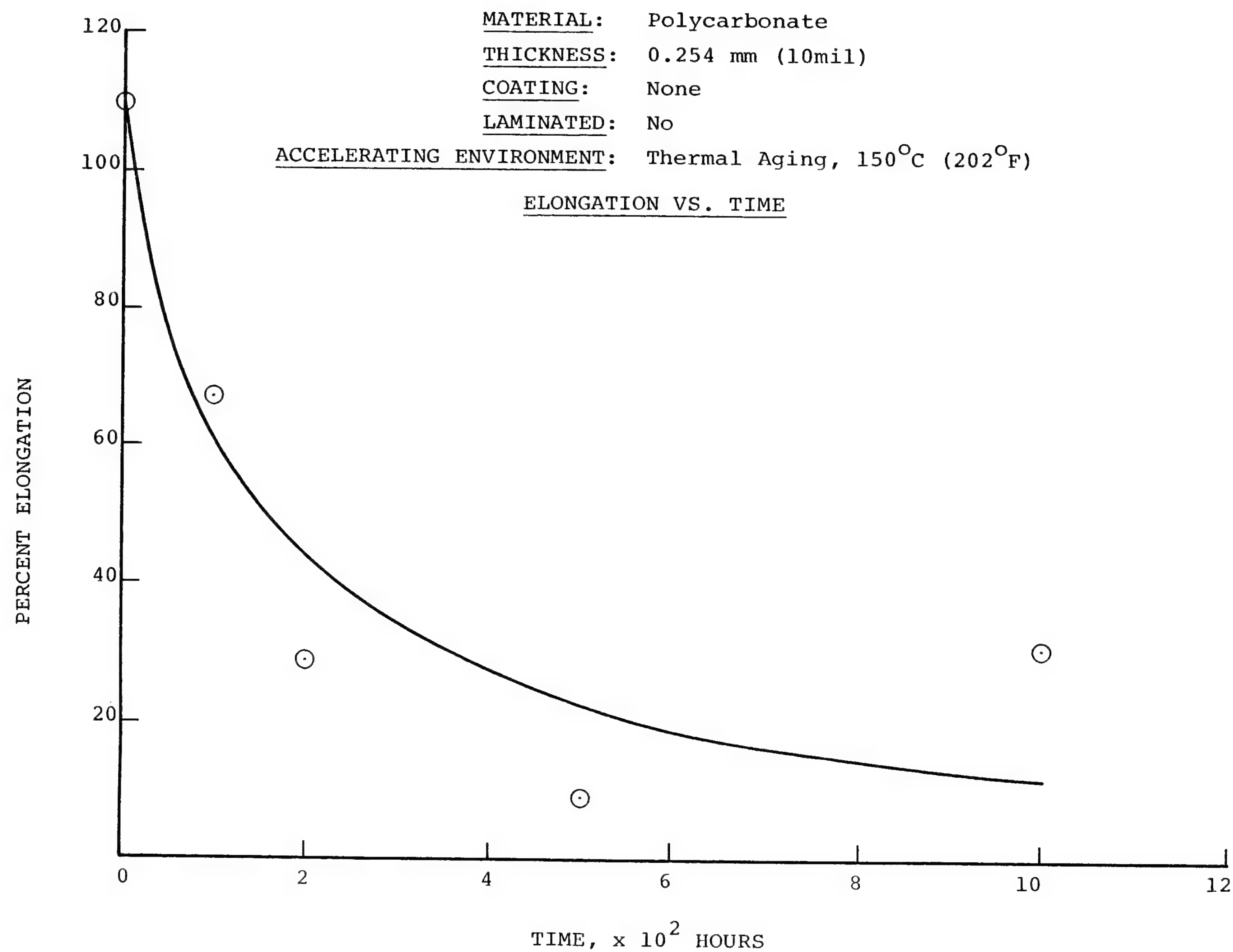
COATING: None

LAMINATED: No

ACCELERATING ENVIRONMENT: Thermal Aging, 150°C (202°F)

YIELD AND BREAK STRENGTH VS. TIME




MATERIAL: Polycarbonate
THICKNESS: 0.254 mm (10mil)
COATING: None
LAMINATED: No
ACCELERATING ENVIRONMENT: Thermal Aging, 150°C (202°F)
ELONGATION VS. TIME
PERCENT ELONGATION
120
100
80
60
40
20
0
2
4
6
8
10
12
TIME, x 10² HOURS

MATERIAL: Polyethersulfone

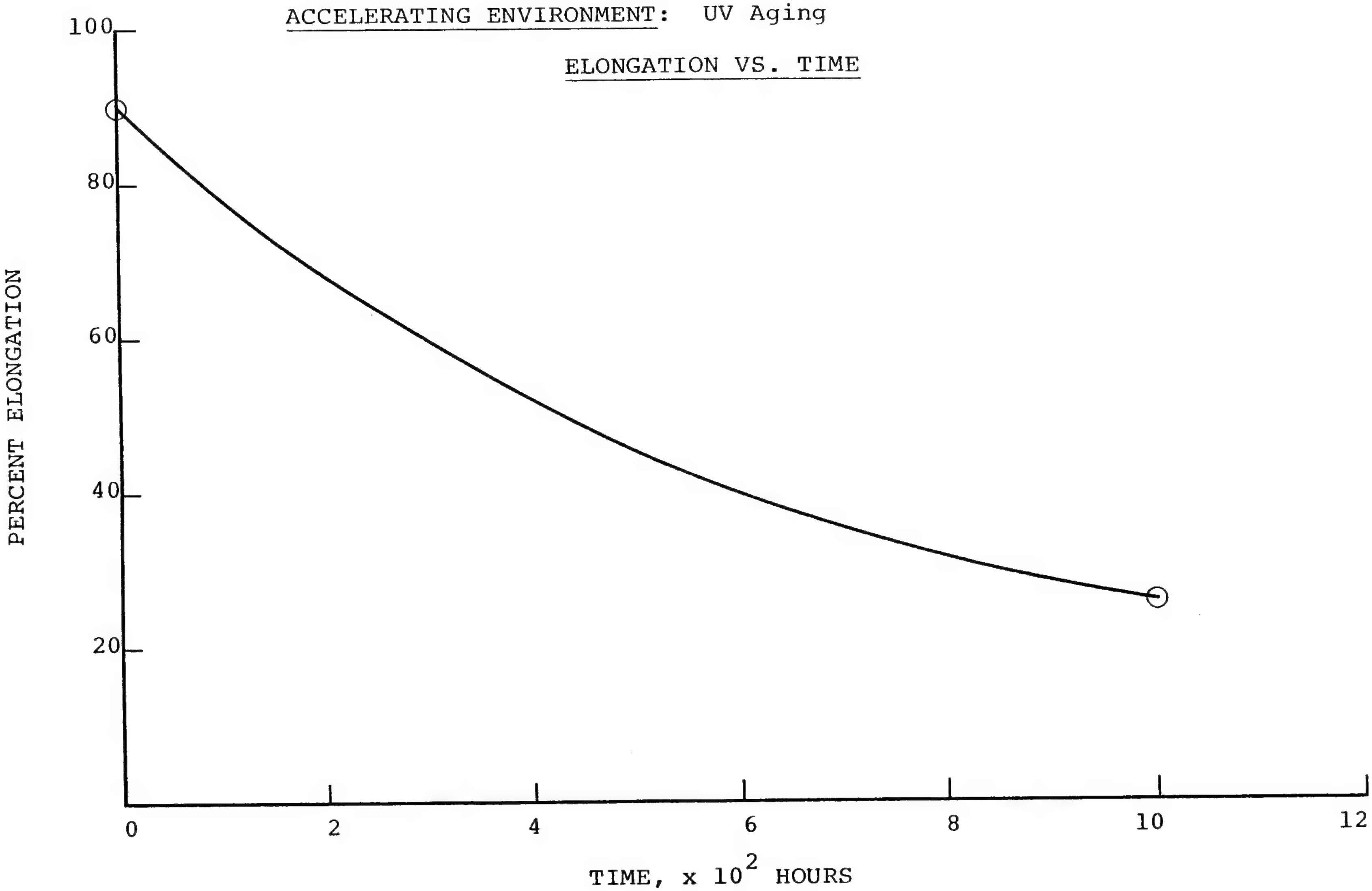
THICKNESS: 0.508 mm (20mil)

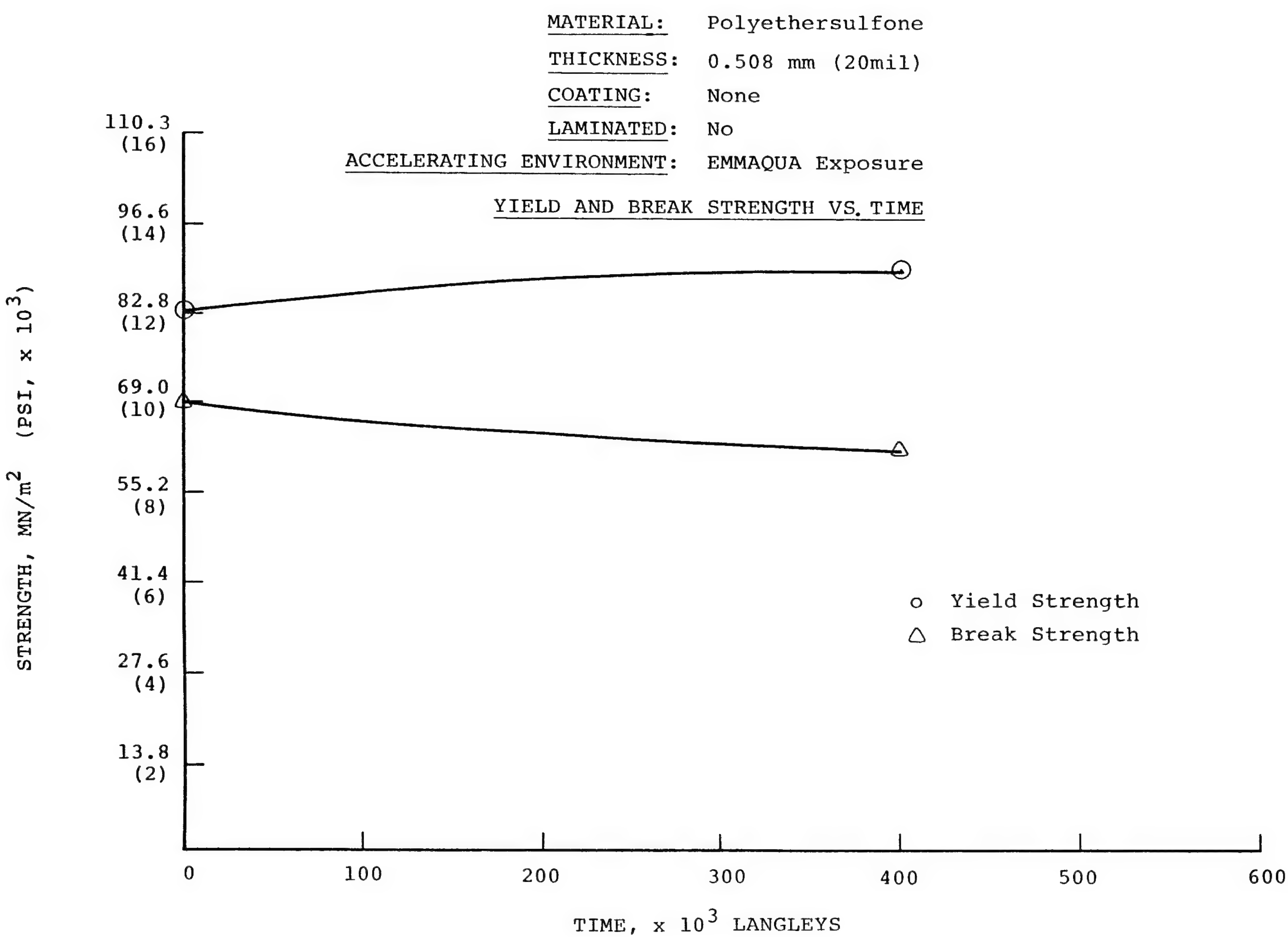
COATING: None

LAMINATED: No

ACCELERATING ENVIRONMENT: UV Aging

ELONGATION VS. TIME





MATERIAL: Polyethersulfone
THICKNESS: 0.508 mm (20mil)
COATING: None
LAMINATED: No
ACCELERATING ENVIRONMENT: EMMAQUA Exposure
YIELD AND BREAK STRENGTH VS. TIME
110.3 (16)
96.6 (14)
82.8 (12)
69.0 (10)
55.2 (8)
41.4 (6)
27.6 (4)
13.8 (2)
STRENGTH, MN/m2 (PSI, x 10^3)
0
100
200
300
400
500
600
TIME, x 10^3 LANGLEYS
o Yield Strength
△ Break Strength

MATERIAL: Polyethersulfone

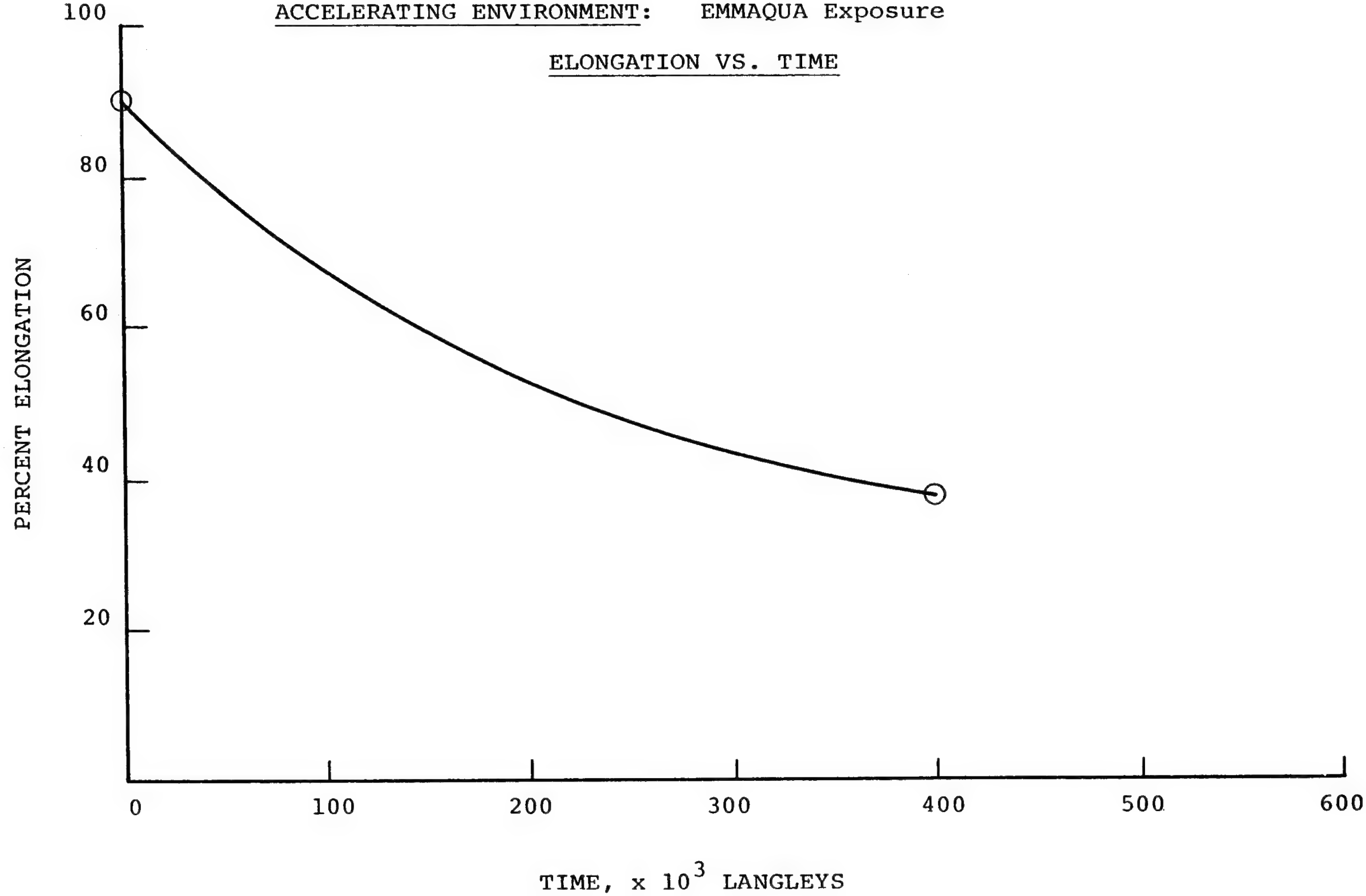
THICKNESS: 0.508 mm (20mil)

COATING: None

LAMINATED: No

ACCELERATING ENVIRONMENT: EMMAQUA Exposure

ELONGATION VS. TIME



MATERIAL: Polyethersulfone

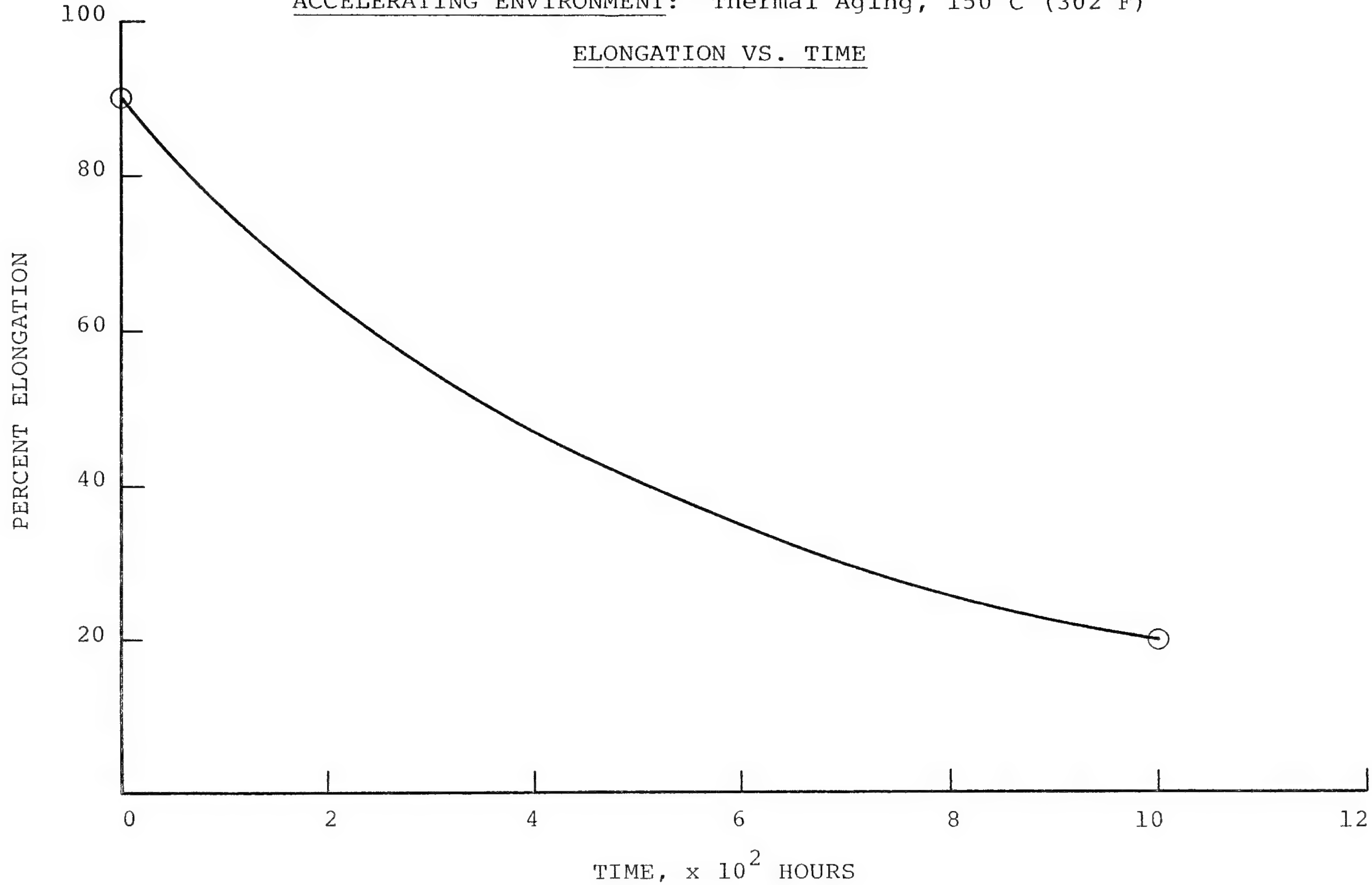
THICKNESS: 0.508 mm (20mil)

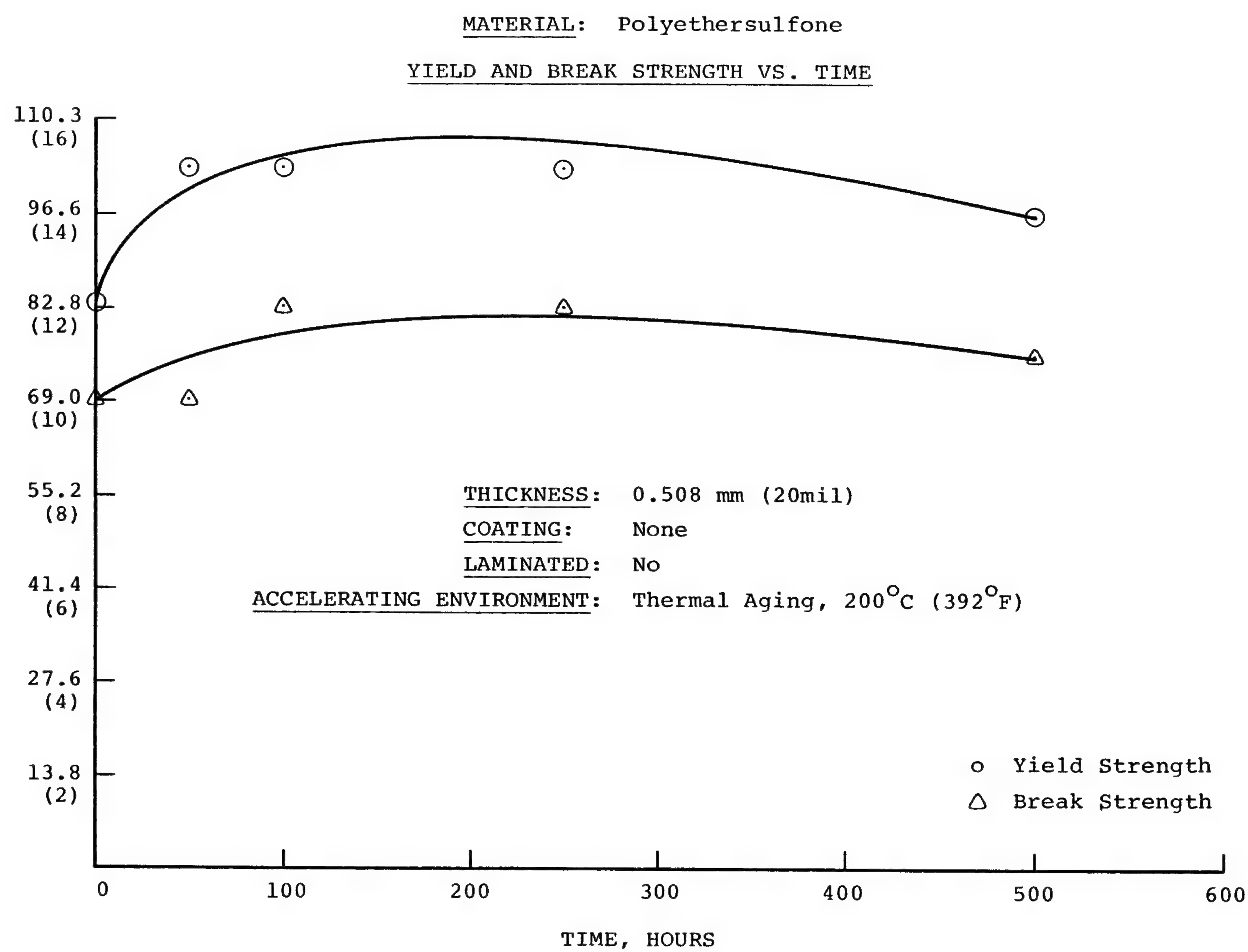
COATING: None

LAMINATED: No

ACCELERATING ENVIRONMENT: Thermal Aging, 150°C (302°F)

ELONGATION VS. TIME





MATERIAL: Polyethersulfone
YIELD AND BREAK STRENGTH VS. TIME
110.3 (16)
96.6 (14)
82.8 (12)
69.0 (10)
55.2 (8)
41.4 (6)
27.6 (4)
13.8 (2)
THICKNESS: 0.508 mm (20mil)
COATING: None
LAMINATED: No
ACCELERATING ENVIRONMENT: Thermal Aging, 200°C (392°F)
o Yield Strength
△ Break Strength
0
100
200
300
400
500
600
TIME, HOURS

MATERIAL: Polyethersulfone

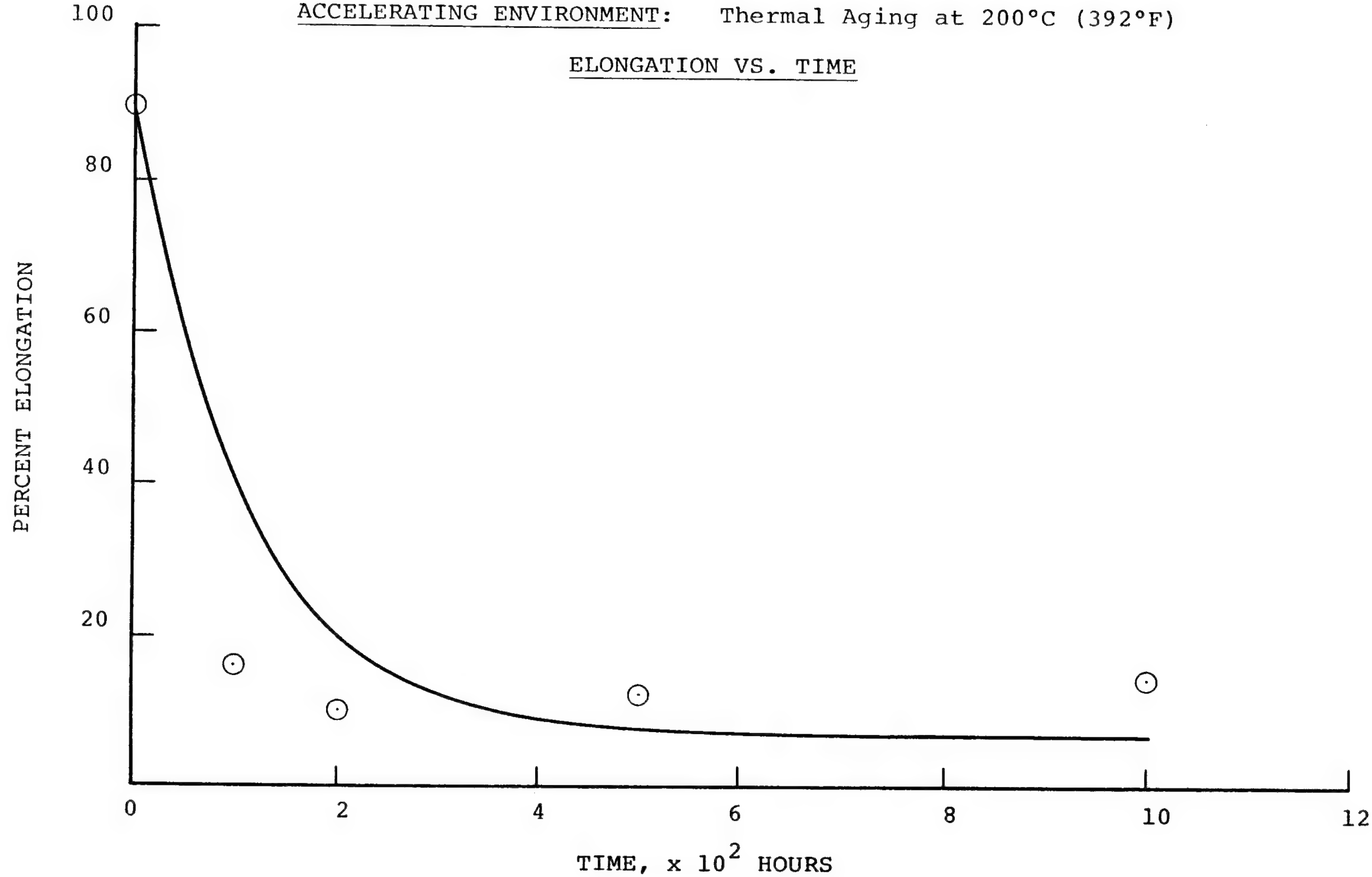
THICKNESS: 0.508 mm (20mil)

COATING: None

LAMINATED: No

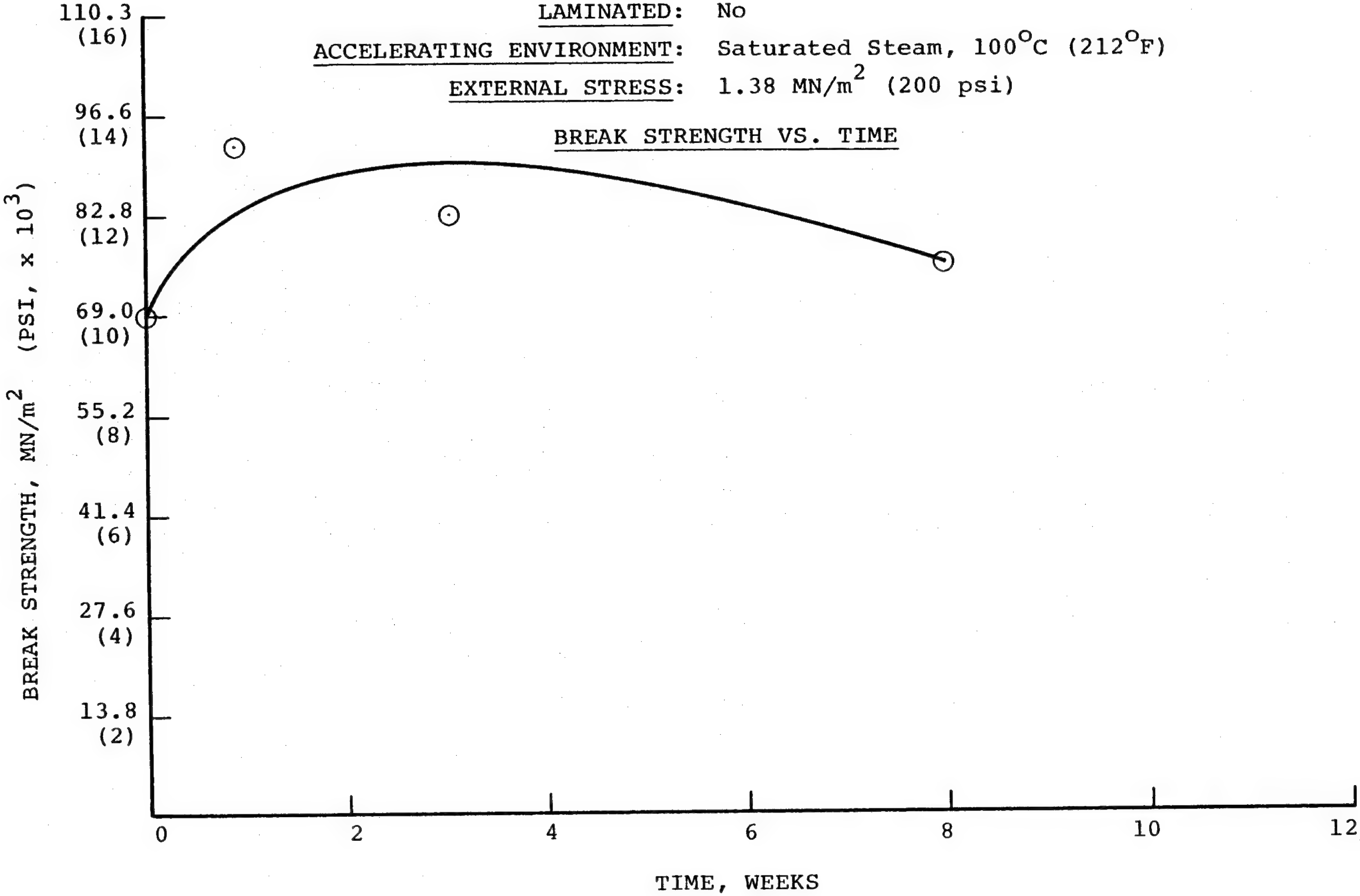
ACCELERATING ENVIRONMENT: Thermal Aging at 200°C (392°F)

ELONGATION VS. TIME



MATERIAL: Polyethersulfone
THICKNESS: 0.508 mm (20mil)
COATING: None
LAMINATED: No
ACCELERATING ENVIRONMENT: Saturated Steam, 100°C (212°F)
EXTERNAL STRESS: 1.38 MN/m^2 (200 psi)

BREAK STRENGTH VS. TIME



MATERIAL: Polyethersulfone

THICKNESS: 0.508 mm (20mil)

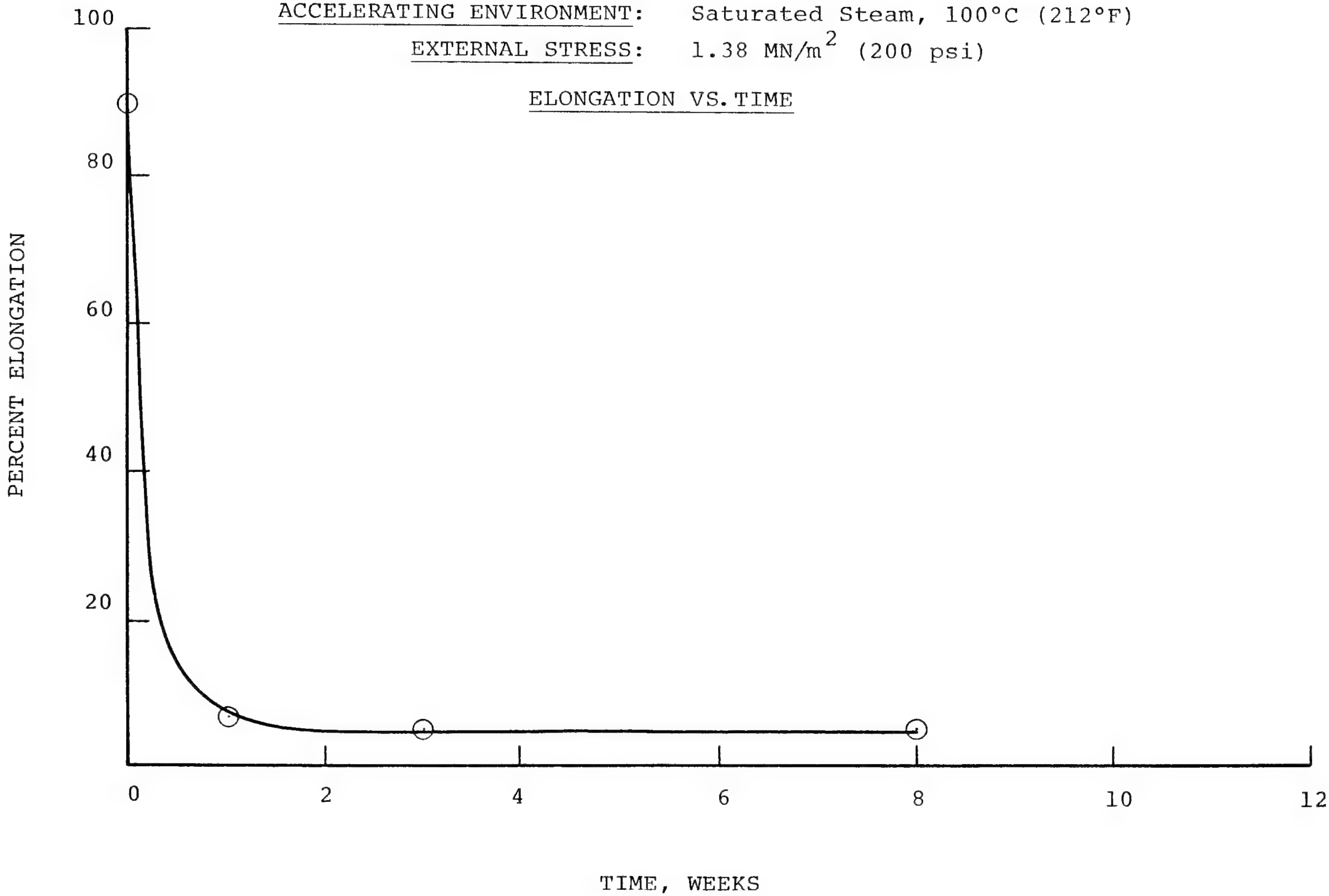
COATING: None

LAMINATED: No

ACCELERATING ENVIRONMENT: Saturated Steam, 100°C (212°F)

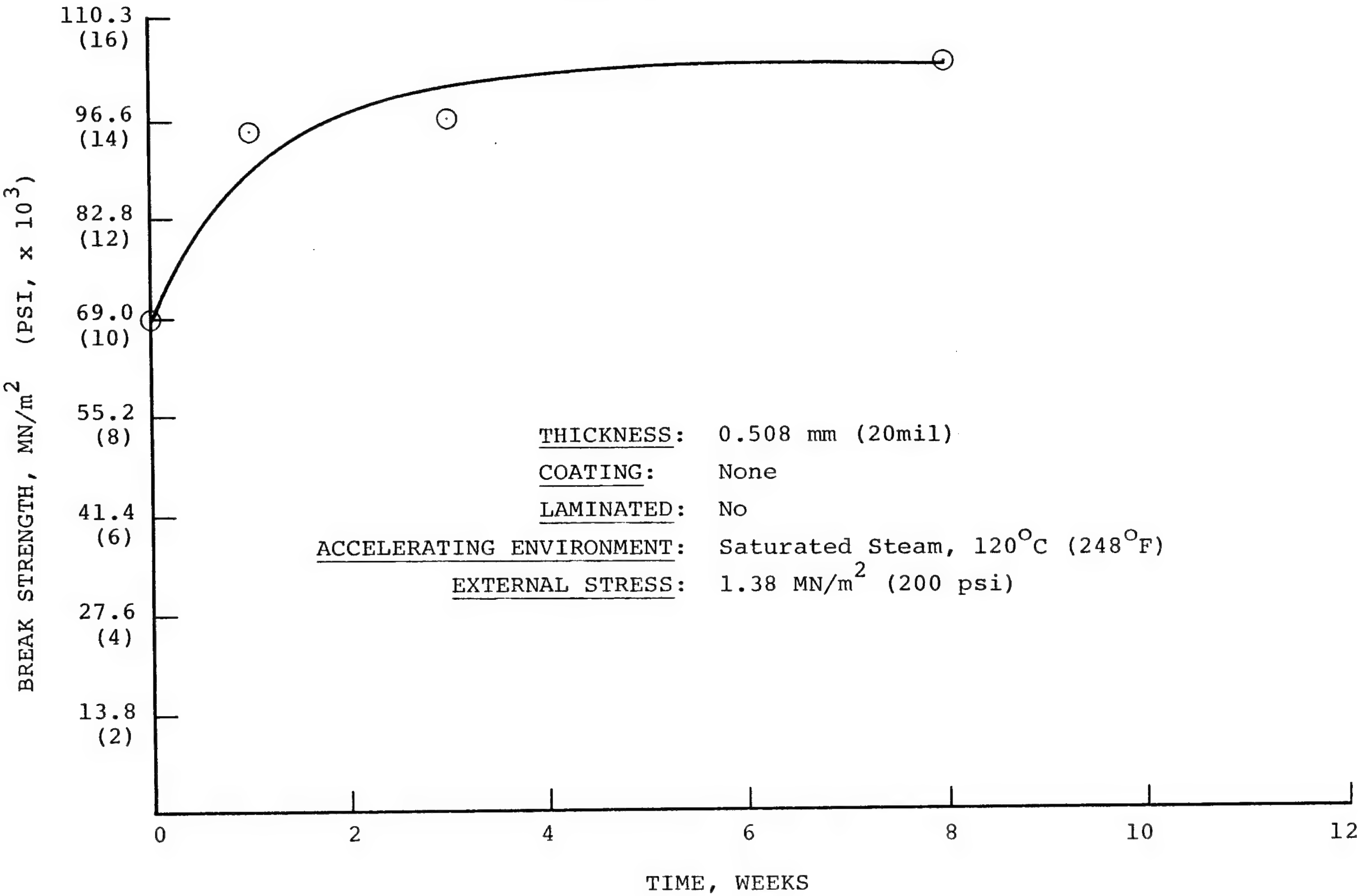
EXTERNAL STRESS: 1.38 MN/m^2 (200 psi)

ELONGATION VS. TIME



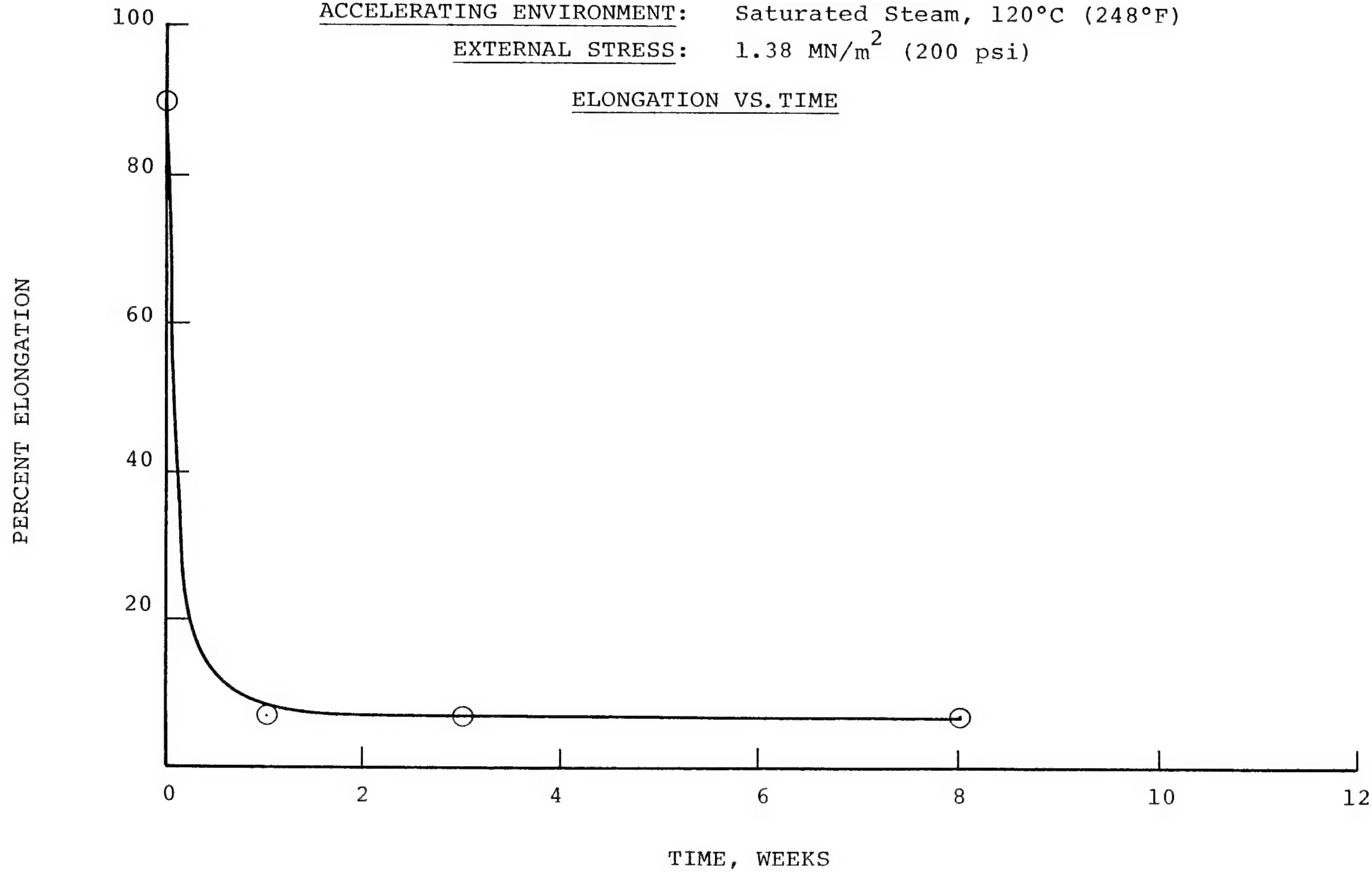
MATERIAL: Polyethersulfone

BREAK STRENGTH VS. TIME



MATERIAL:	Polyethersulfone
THICKNESS:	0.508 mm (20mil)
COATING:	None
LAMINATED:	No
ACCELERATING ENVIRONMENT:	Saturated Steam, 120°C (248°F)
EXTERNAL STRESS:	1.38 MN/m^2 (200 psi)

ELONGATION VS. TIME



MATERIAL: Polyethersulfone

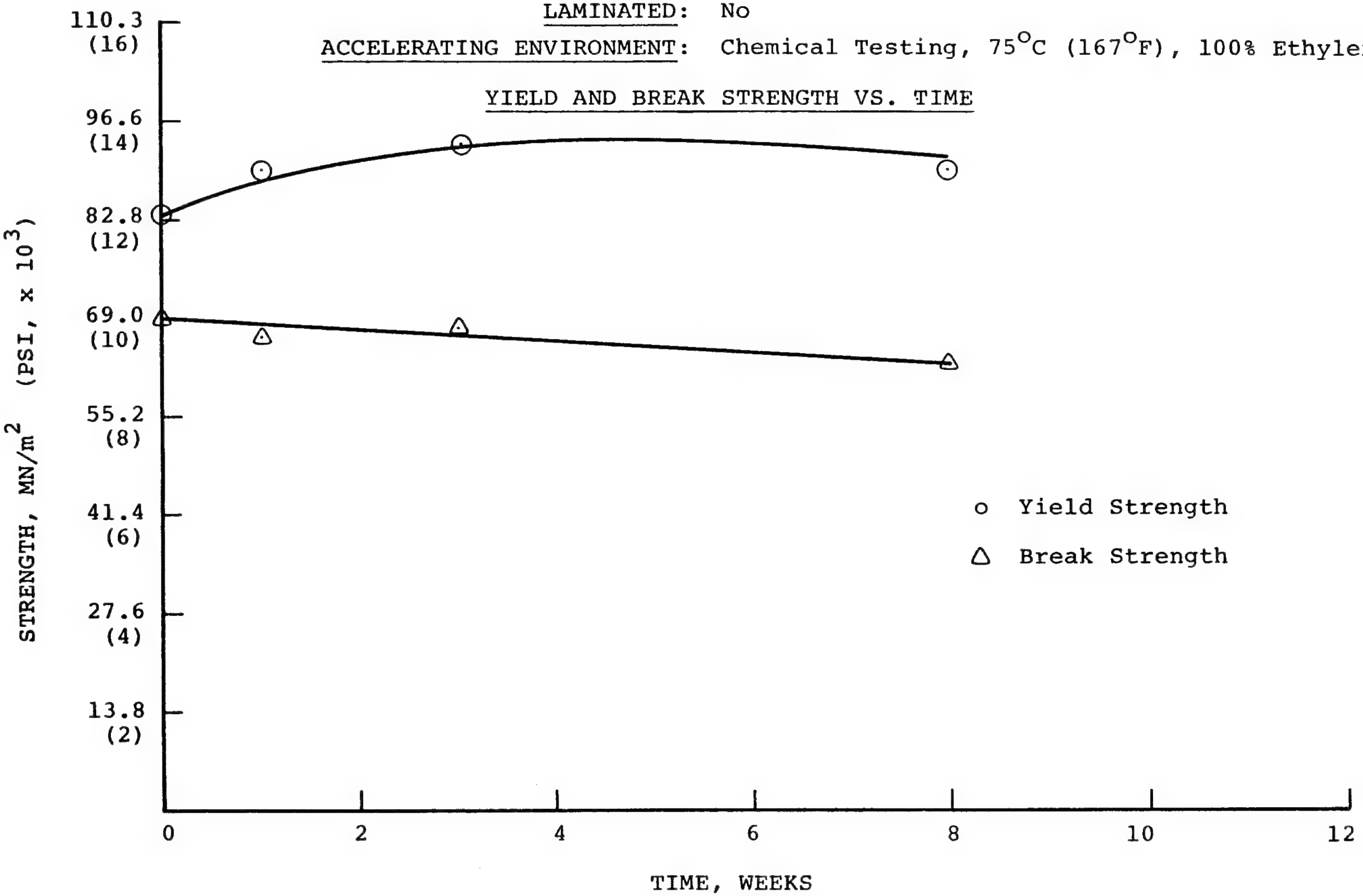
THICKNESS: 0.508 mm (20mil)

COATING: None

LAMINATED: No

ACCELERATING ENVIRONMENT: Chemical Testing, 75°C (167°F), 100% Ethylene Glycol

YIELD AND BREAK STRENGTH VS. TIME



MATERIAL: Polyethersulfone

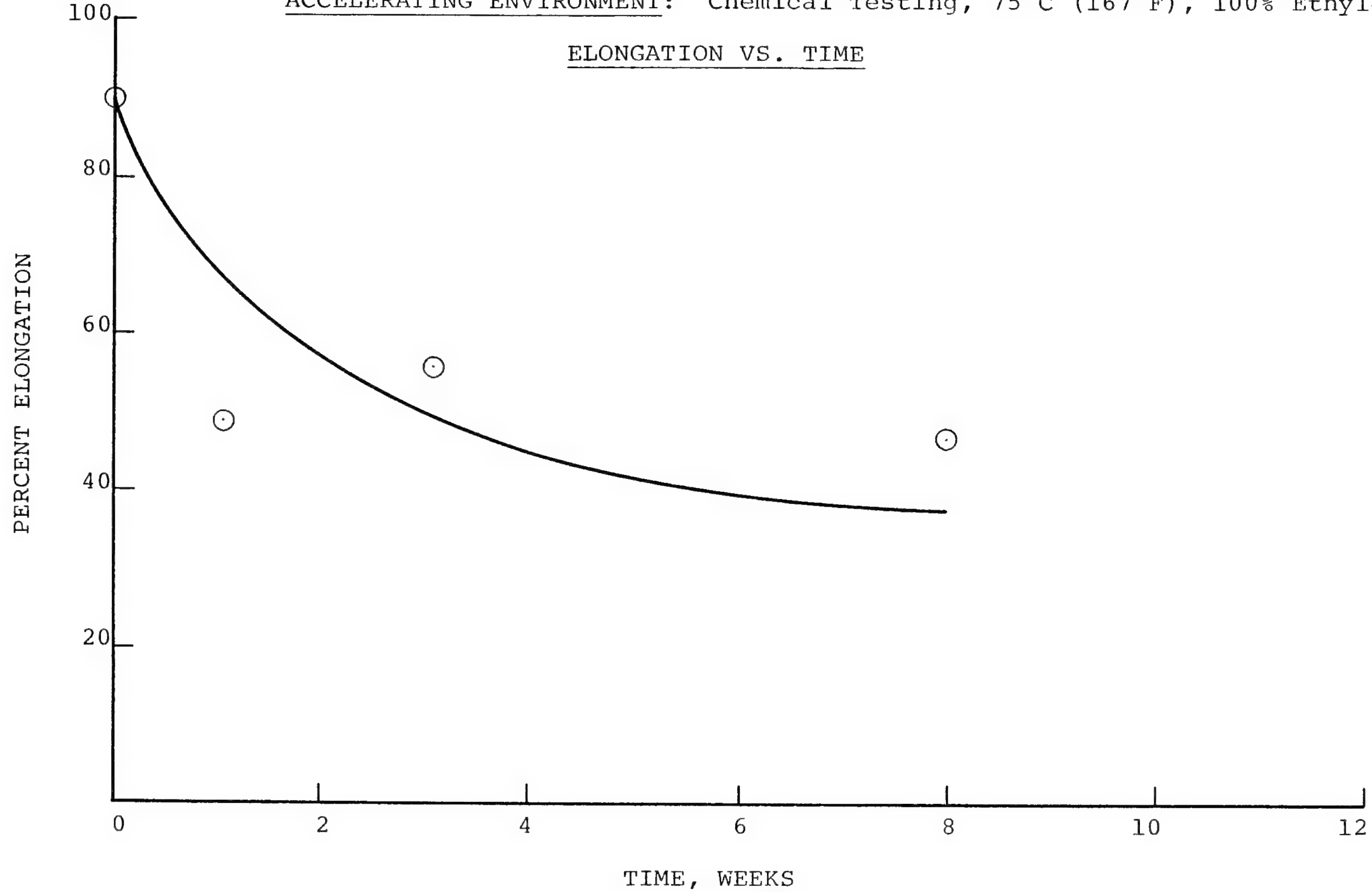
THICKNESS: 0.508 mm (20mil)

COATING: None

LAMINATED: No

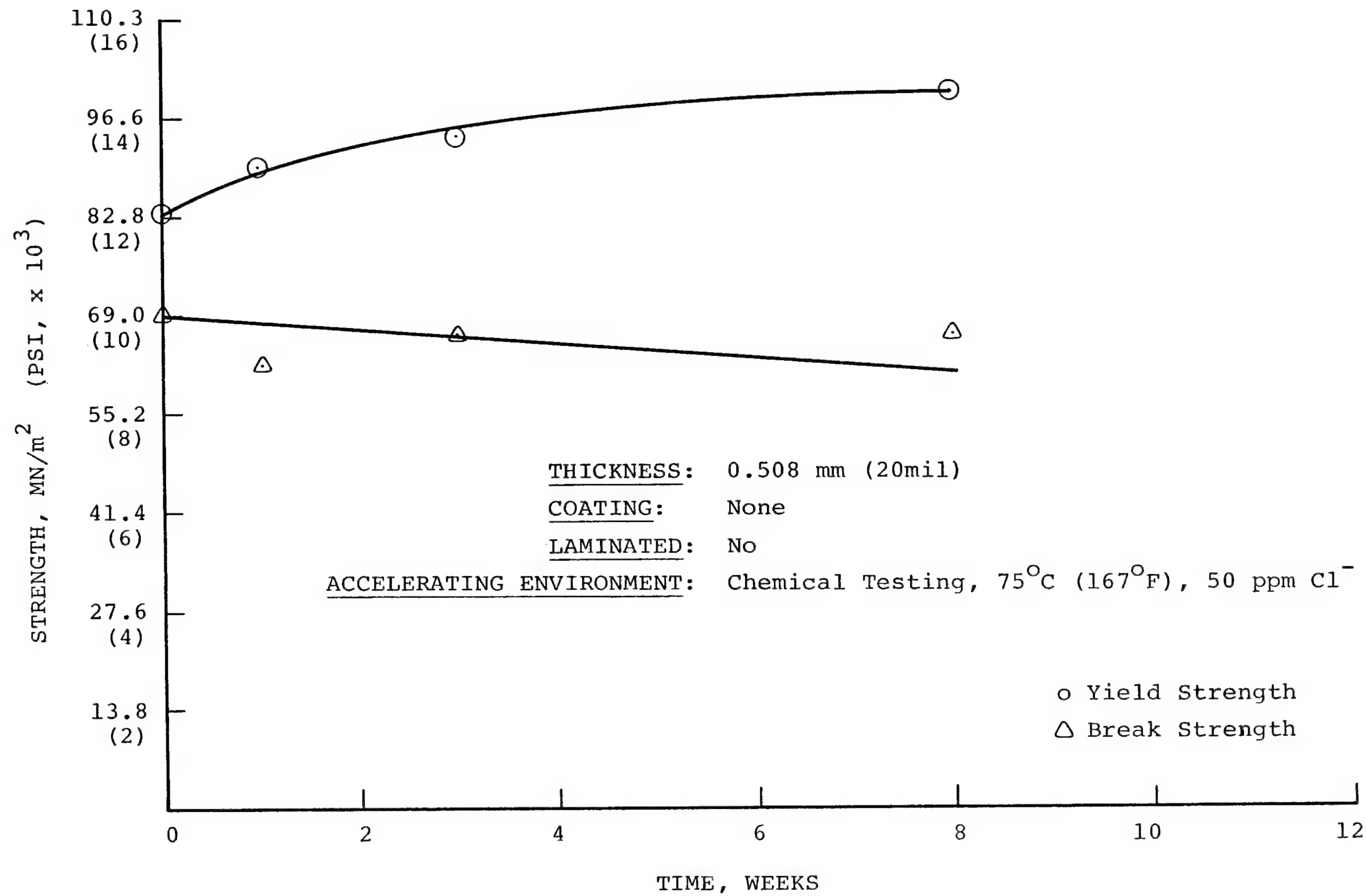
ACCELERATING ENVIRONMENT: Chemical Testing, 75°C (167°F), 100% Ethylene Glycol

ELONGATION VS. TIME



MATERIAL: Polyethersulfone

YIELD AND BREAK STRENGTH VS. TIME



MATERIAL: Polyethersulfone

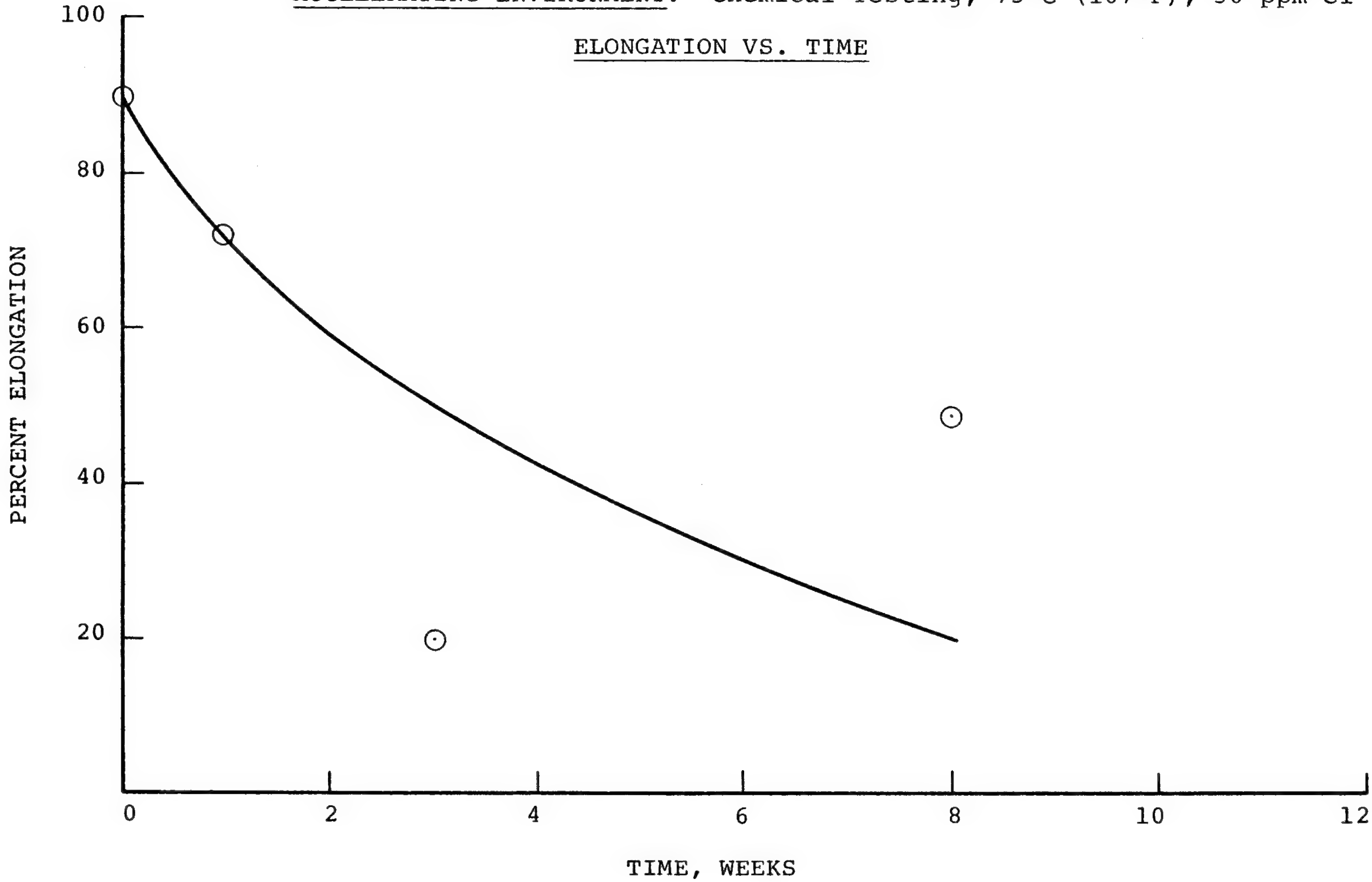
THICKNESS: 0.508 mm (20mil)

COATING: None

LAMINATED: No

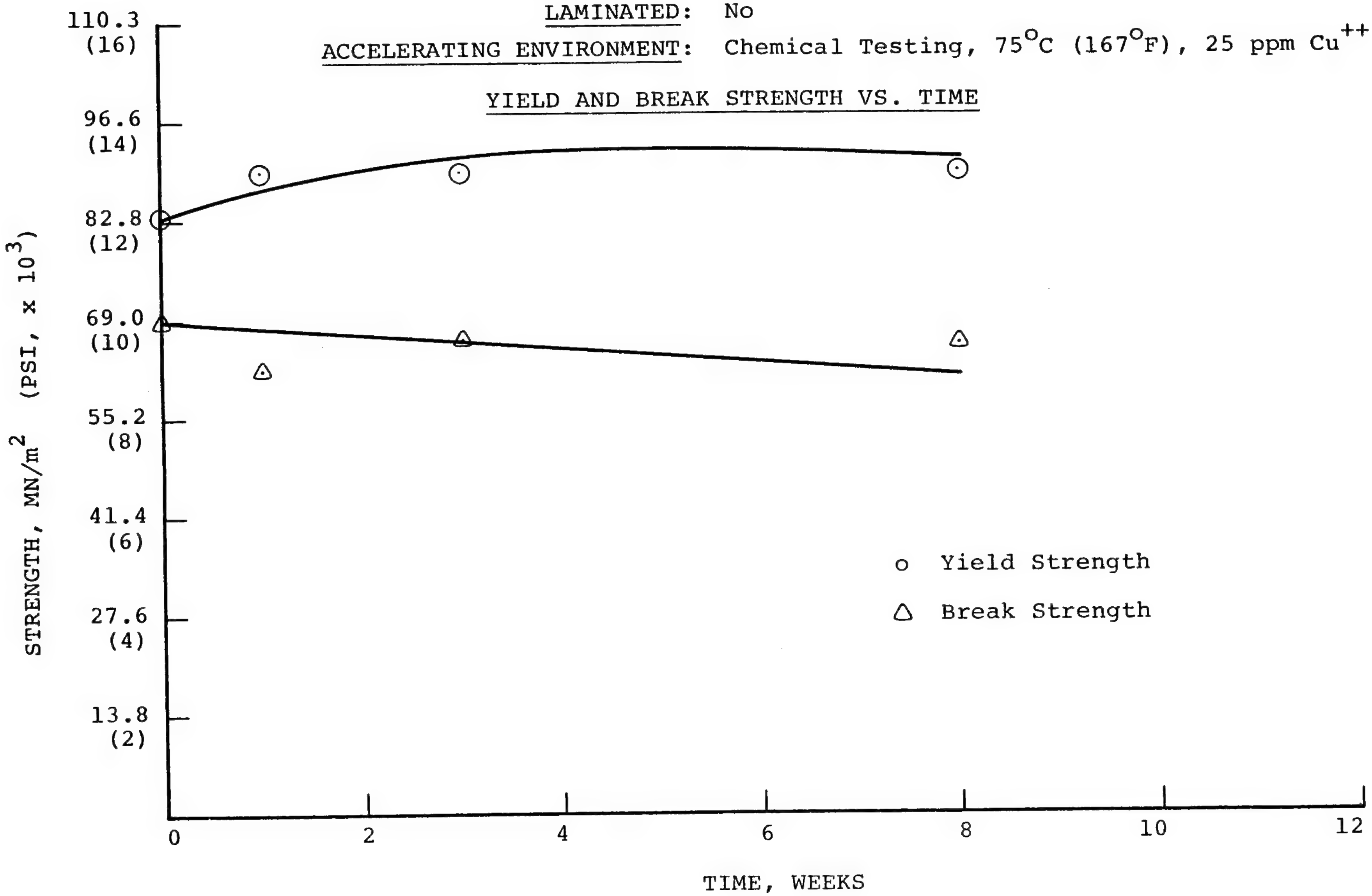
ACCELERATING ENVIRONMENT: Chemical Testing, 75°C (167°F), 50 ppm Cl^-

ELONGATION VS. TIME



MATERIAL: Polyethersulfone
THICKNESS: 0.508 mm (20mil)
COATING: None
LAMINATED: No
ACCELERATING ENVIRONMENT: Chemical Testing, 75°C (167°F), 25 ppm Cu^{++}

YIELD AND BREAK STRENGTH VS. TIME



MATERIAL: Polyethersulfone

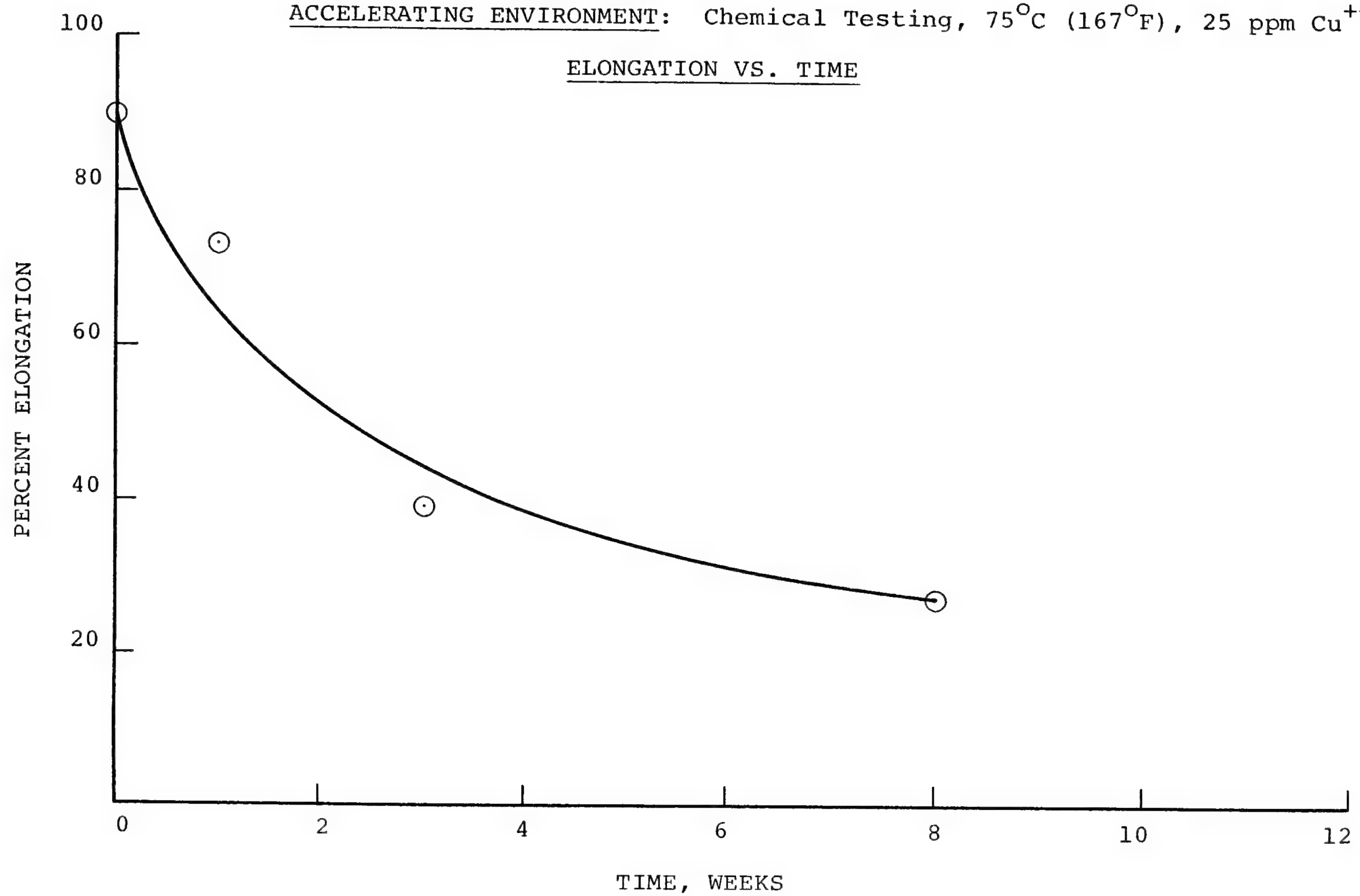
THICKNESS: 0.508 mm (20mil)

COATING: None

LAMINATED: No

ACCELERATING ENVIRONMENT: Chemical Testing, 75°C (167°F), 25 ppm Cu^{++}

ELONGATION VS. TIME



MATERIAL: Polyarylate

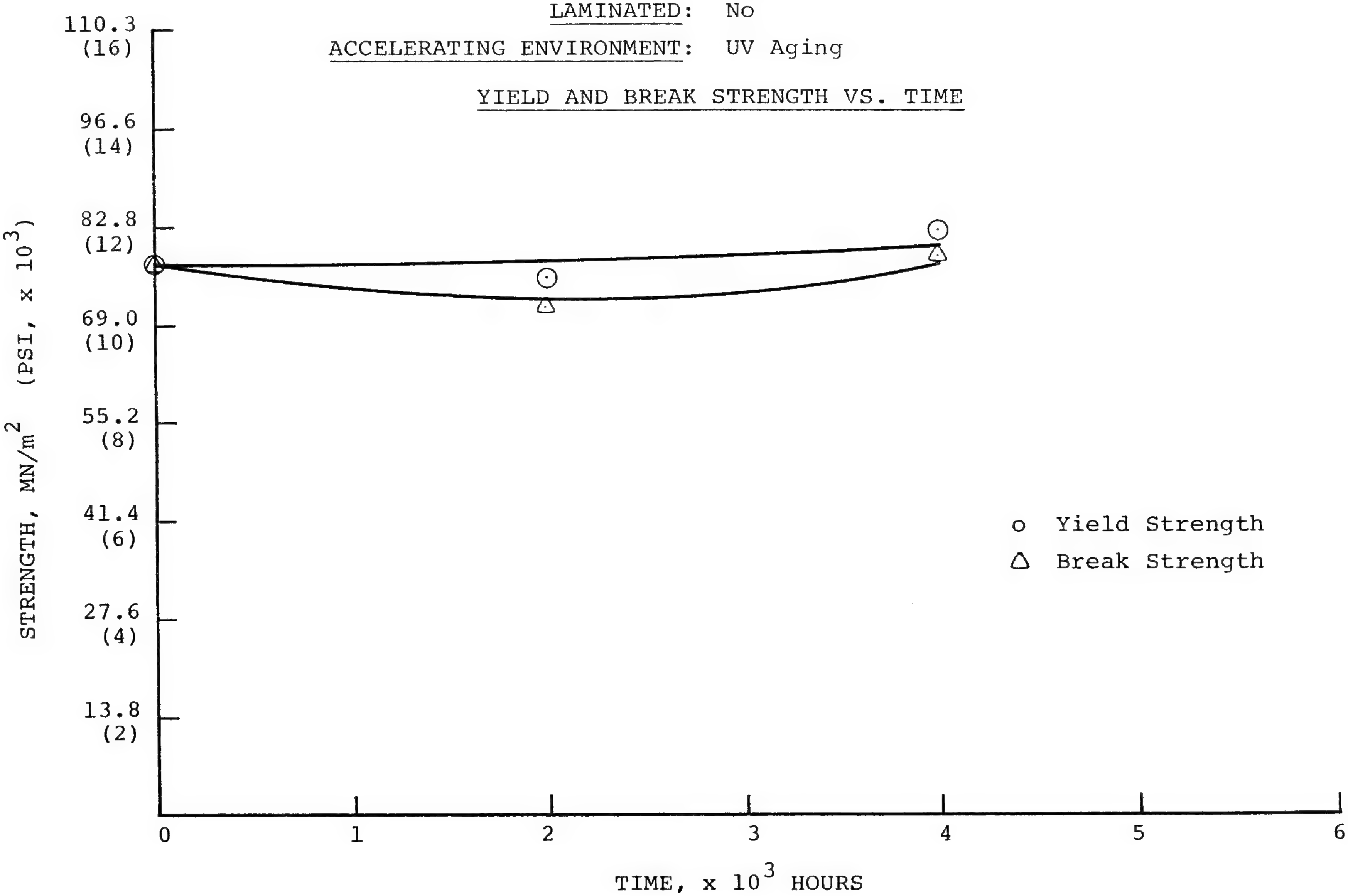
THICKNESS: 0.127 mm (5mil)

COATING: None

LAMINATED: No

ACCELERATING ENVIRONMENT: UV Aging

YIELD AND BREAK STRENGTH VS. TIME



MATERIAL: Polyarylate

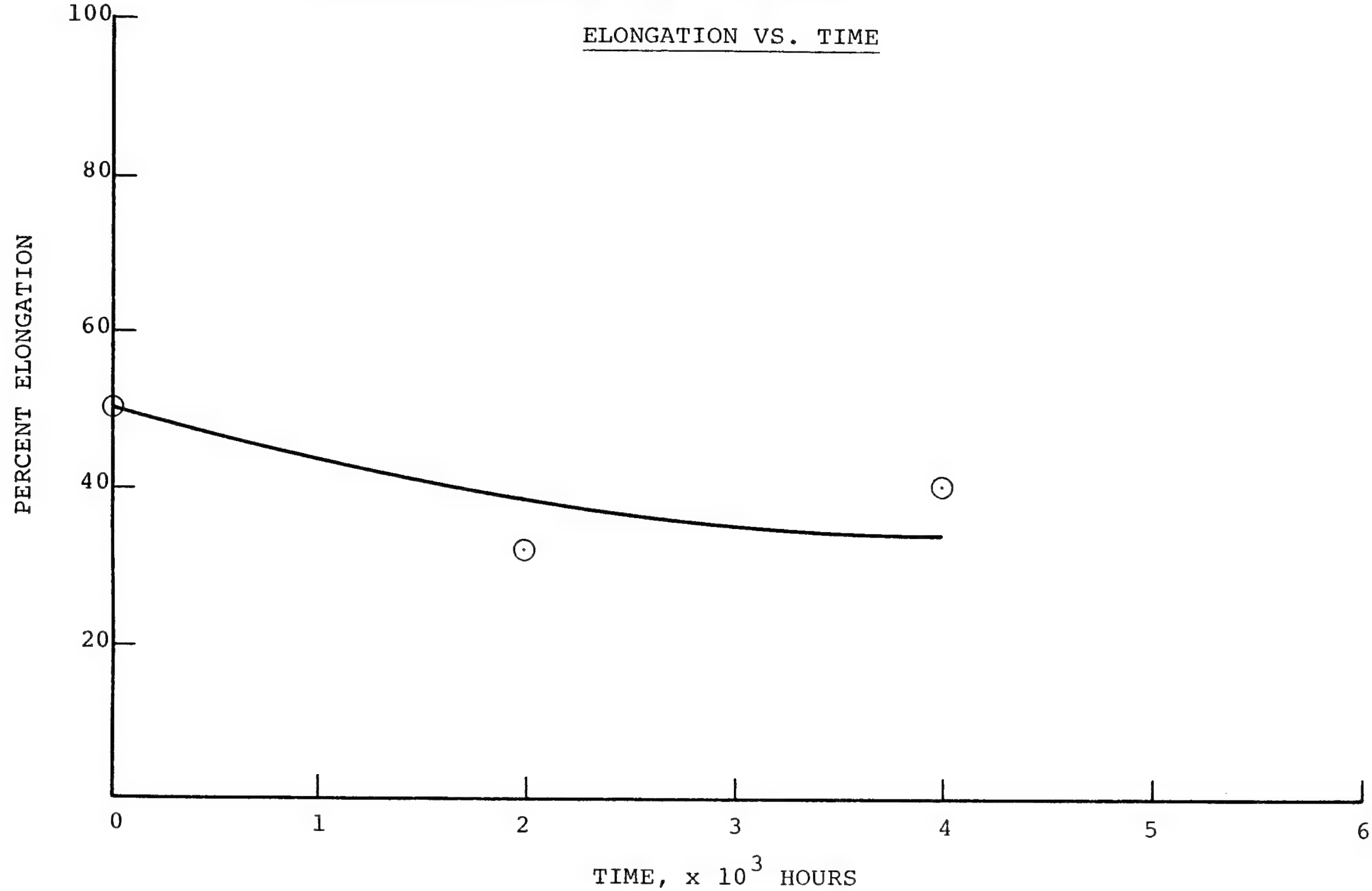
THICKNESS: 0.127 mm (5mil)

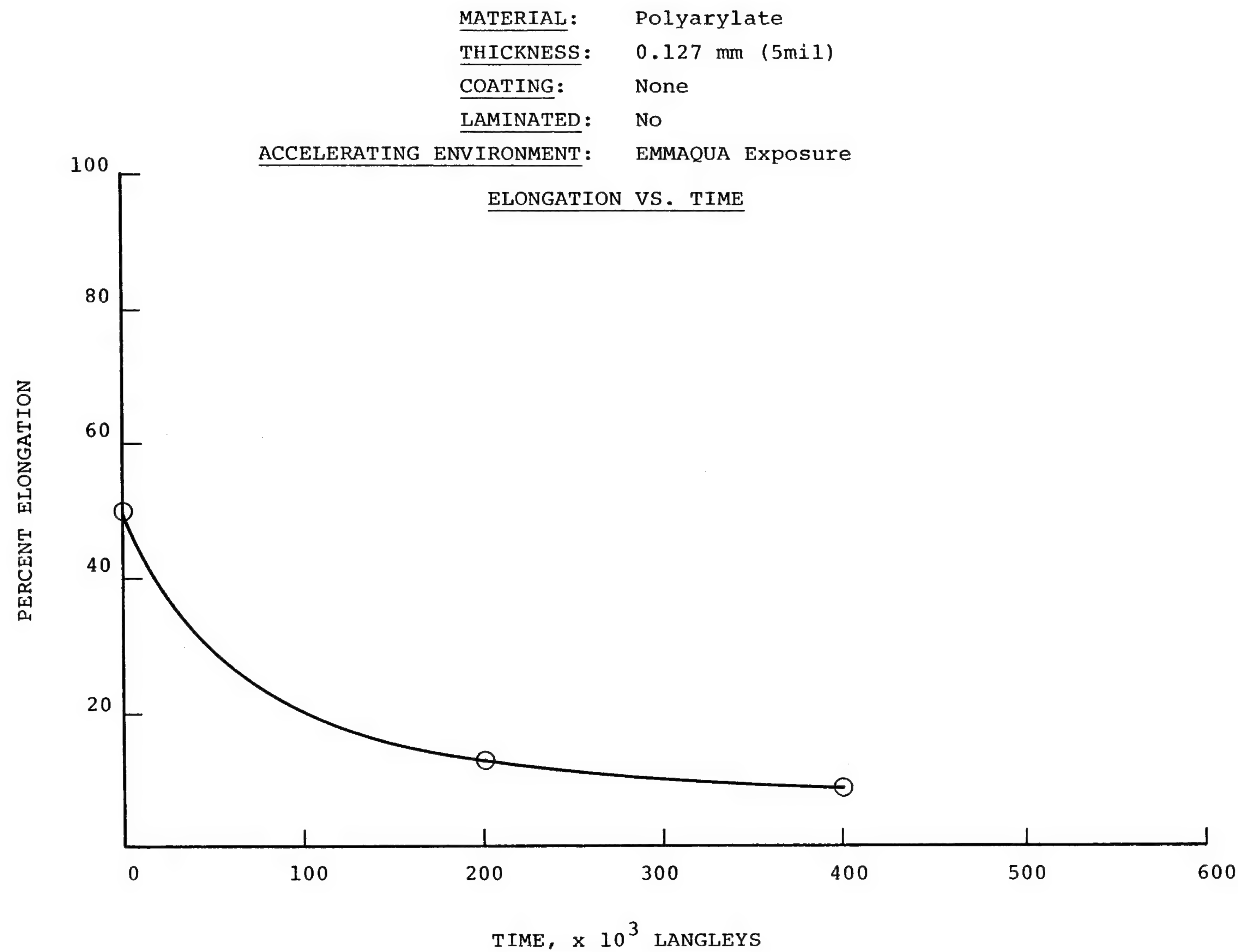
COATING: None

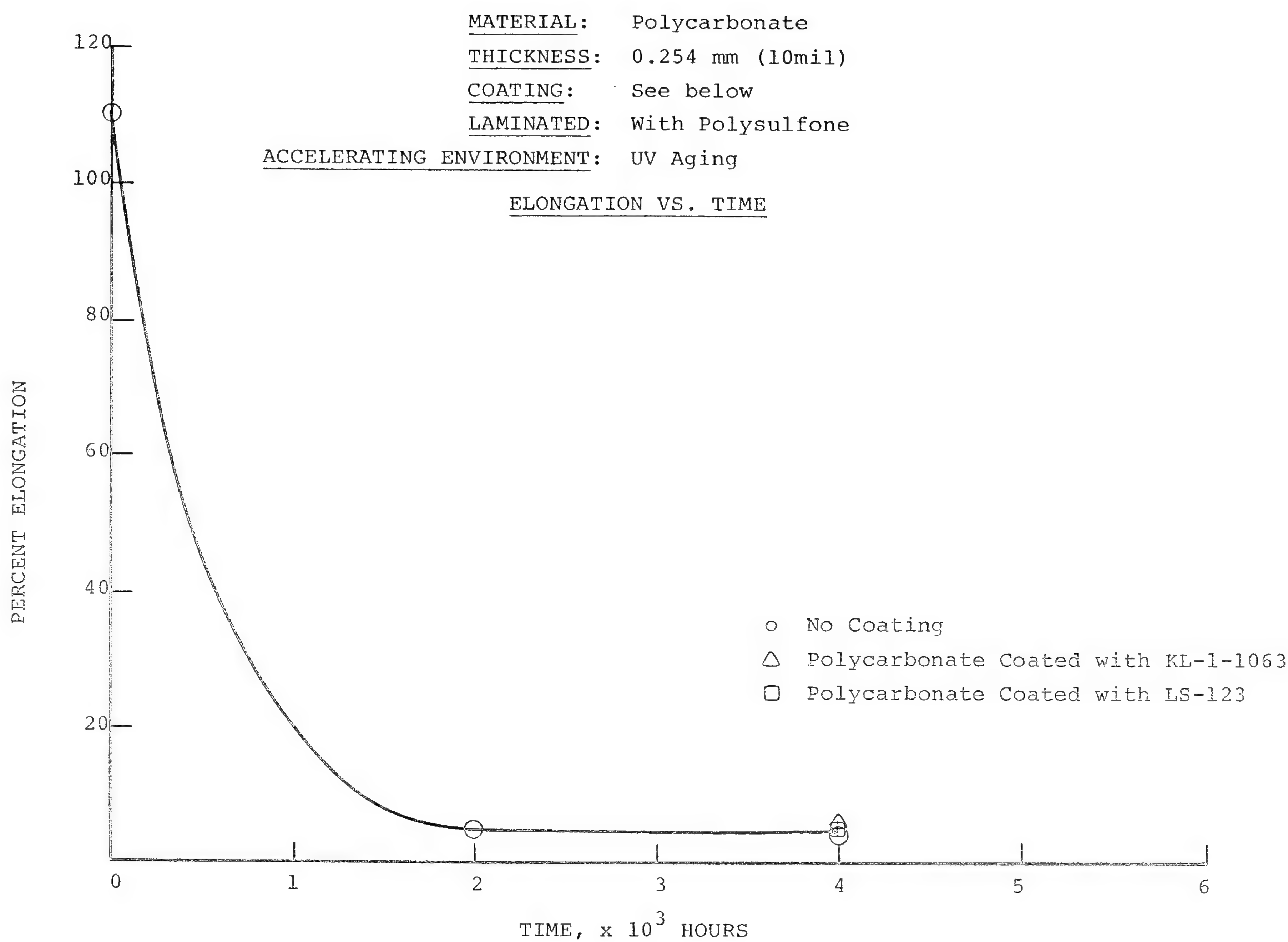
LAMINATED: No

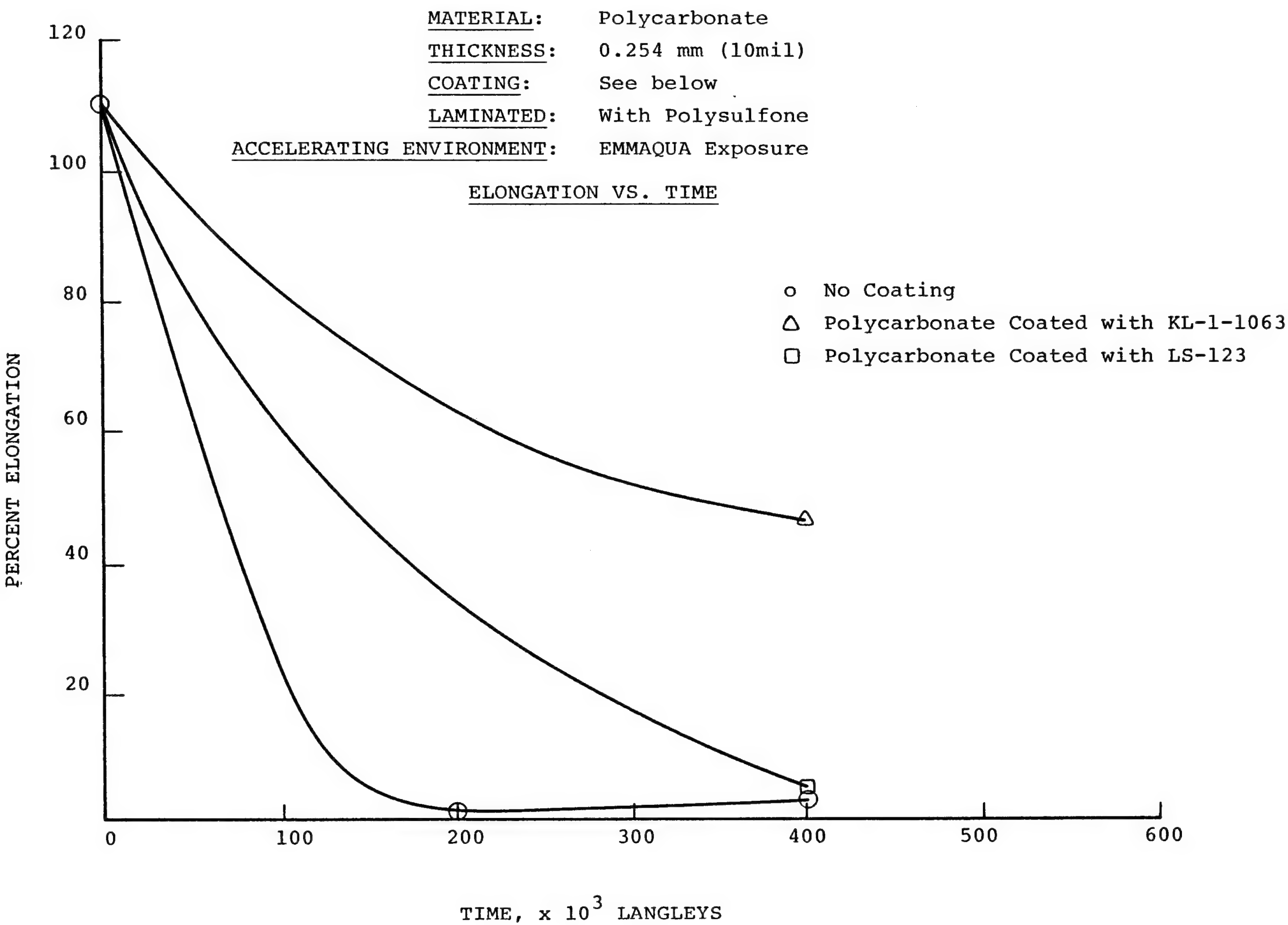
ACCELERATING ENVIRONMENT: UV Aging

ELONGATION VS. TIME




MATERIAL: Polyarylate
THICKNESS: 0.127 mm (5mil)
COATING: None
LAMINATED: No
ACCELERATING ENVIRONMENT: EMMAQUA Exposure
ELONGATION VS. TIME
PERCENT ELONGATION
100
80
60
40
20
0
100
200
300
400
500
600
TIME, x 10^3 LANGLEYS


MATERIAL: Polycarbonate
THICKNESS: 0.254 mm (10mil)
COATING: See below
LAMINATED: With Polysulfone
ACCELERATING ENVIRONMENT: UV Aging
ELONGATION VS. TIME
PERCENT ELONGATION
120
100
80
60
40
20
0
1
2
3
4
5
6
TIME, x 10^3 HOURS
○ No Coating
△ Polycarbonate Coated with KL-1-1063
□ Polycarbonate Coated with LS-123


MATERIAL: Polycarbonate
THICKNESS: 0.254 mm (10mil)
COATING: See below
LAMINATED: With Polysulfone
ACCELERATING ENVIRONMENT: EMMAQUA Exposure
ELONGATION VS. TIME
o No Coating
△ Polycarbonate Coated with KL-1-1063
□ Polycarbonate Coated with LS-123
PERCENT ELONGATION
120
100
80
60
40
20
0
100
200
300
400
500
600
TIME, x 10^3 LANGLEYS

MATERIAL: Polyarylate

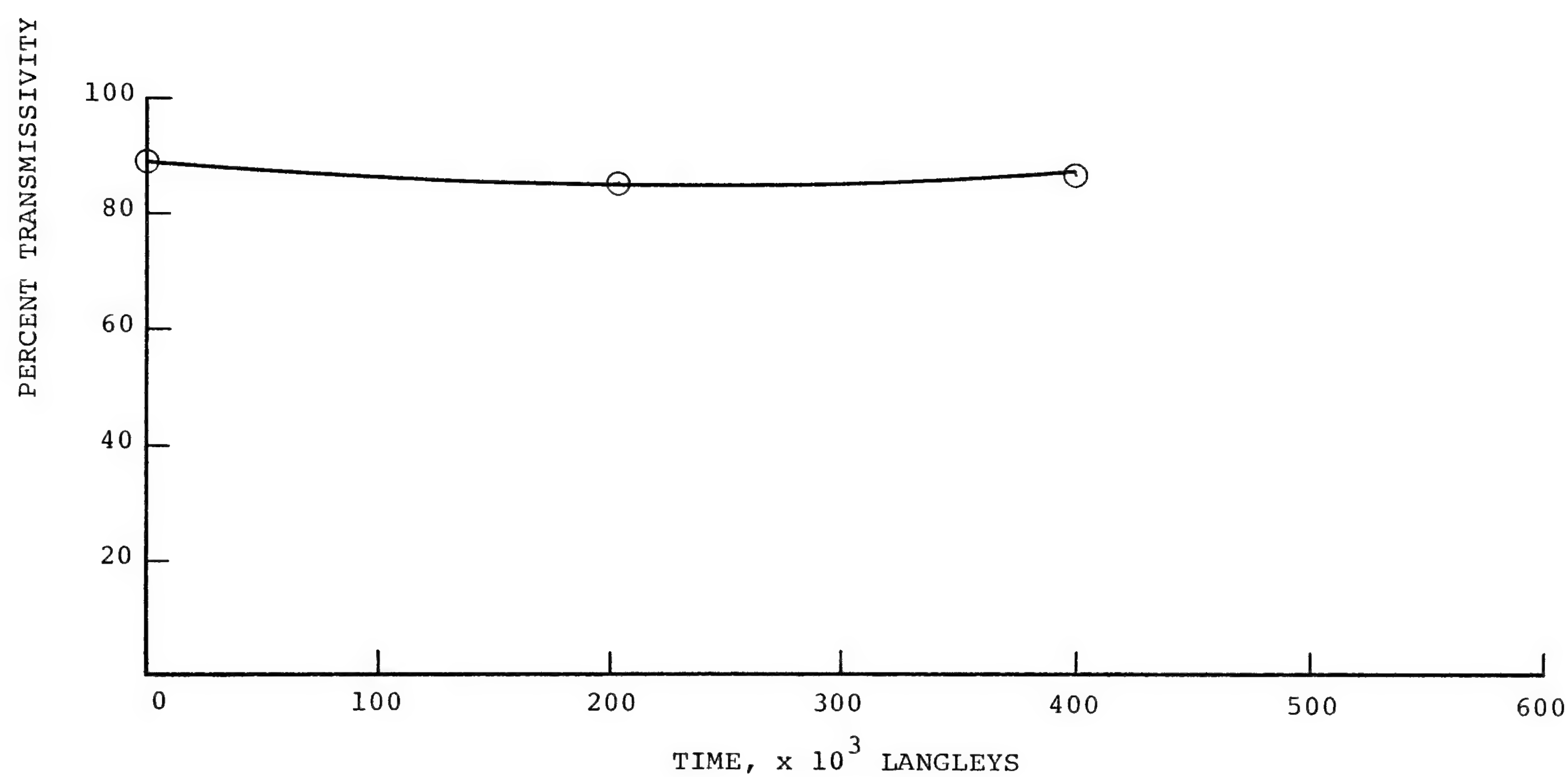
THICKNESS: 0.127 mm (5mil)

COATING: None

LAMINATED: With Polyethersulfone

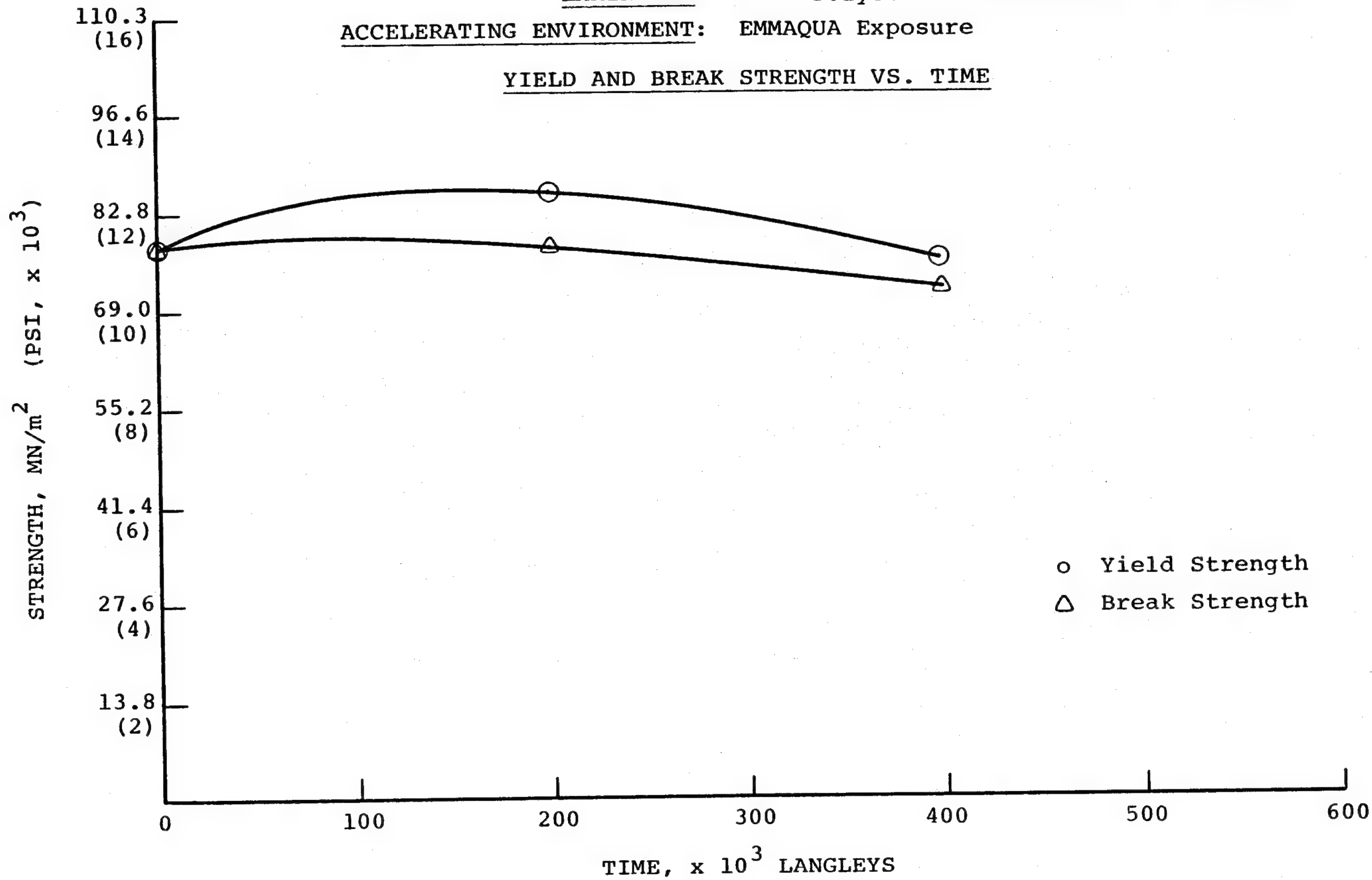
ACCELERATING ENVIRONMENT: EMMAQUA Exposure

TRANSMISSIVITY VS. TIME



MATERIAL: Polyarylate
THICKNESS: 0.127 mm (5mil)
COATING: None
LAMINATED: With Polyethersulfone 0.508 mm (20mil)
ACCELERATING ENVIRONMENT: EMMAQUA Exposure

YIELD AND BREAK STRENGTH VS. TIME



MATERIAL: Polyethersulfone

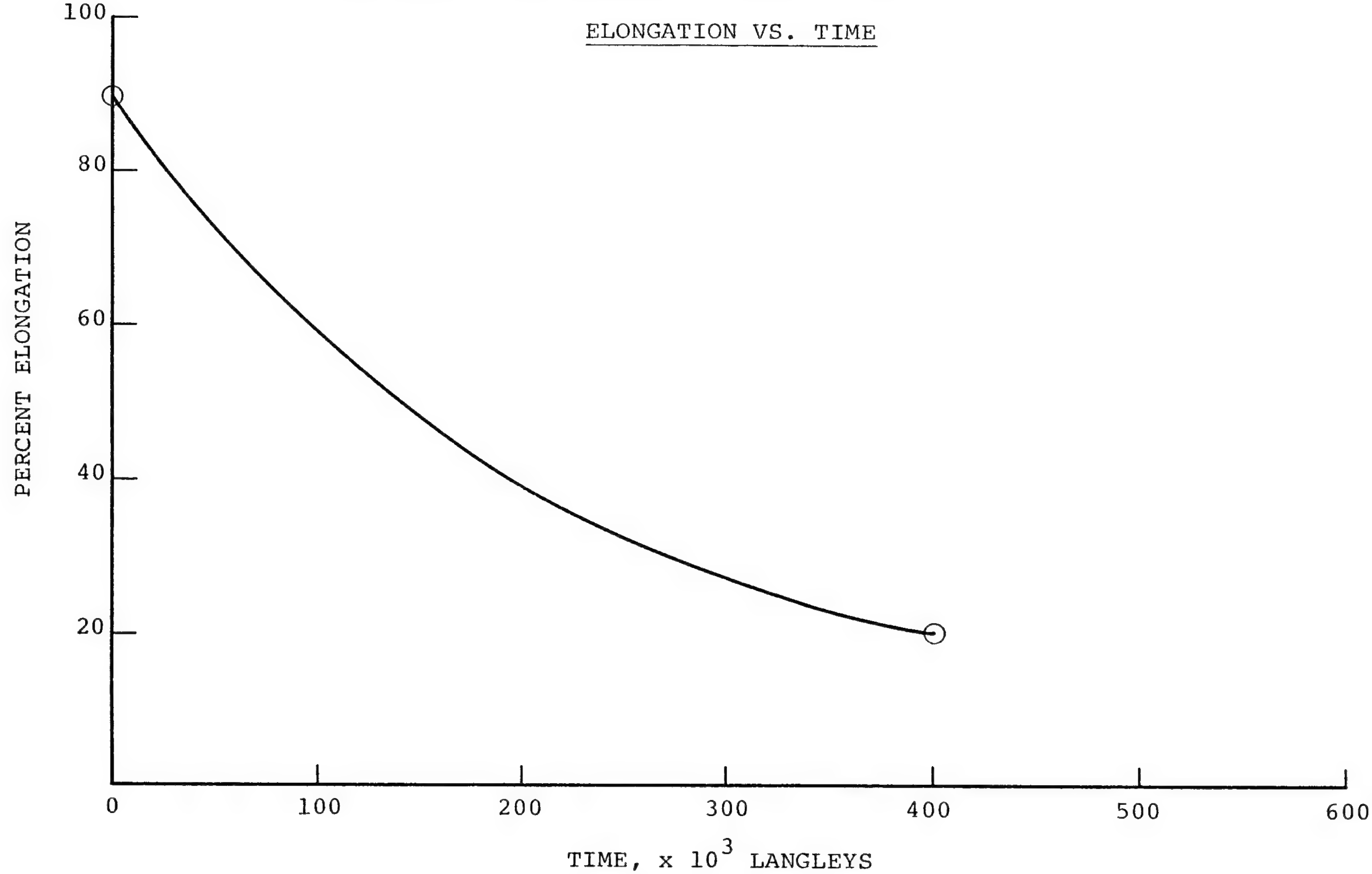
THICKNESS: 0.508 mm (20mil)

COATING: None

LAMINATED: With Polyarylate 0.127 mm (5mil)

ACCELERATING ENVIRONMENT: EMMAQUA Exposure

ELONGATION VS. TIME



MATERIAL: Polyarylate

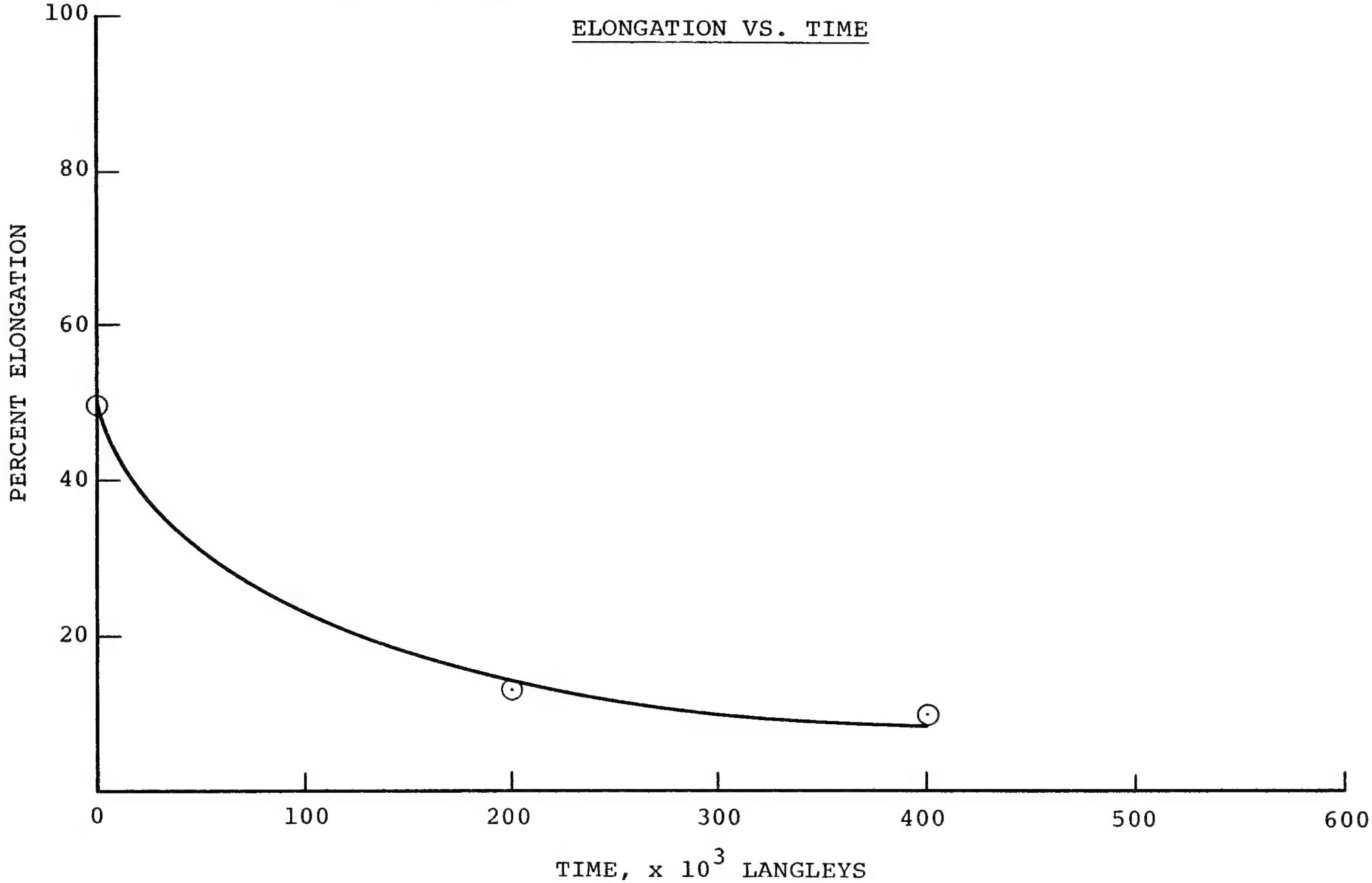
THICKNESS: 0.127 mm (5mil)

COATING: None

LAMINATED: With Polyethersulfone 0.508 mm (20mil)

ACCELERATING ENVIRONMENT: EMMAQUA Exposure

ELONGATION VS. TIME



MATERIALS EVALUATION

TABLES

TRANSMISSIVITY AND TENSILE TESTING

MATERIAL: Polycarbonate
THICKNESS: 0.127 mm (5mil)
COATING: None
LAMINATED: No
ACCELERATING ENVIRONMENT: UV Aging

EXPOSURE TIME OR DOSAGE	YIELD STRENGTH MN/m^2	YIELD STRENGTH (psi)	BREAK STRENGTH MN/m^2	BREAK STRENGTH (psi)	ELONGATION PERCENT	TRANSMISSIVITY PERCENT
0	65.5	(9500)	68.3	(9900)	110	91
1000 hours	-	-	60.0	(8700)	10	90
2000 Hours	62.8	(9100)	60.7	(8800)	7	90
3000 hours	-	-	78.6	(11400)	5	88
4000 hours	-	-	61.7	(7500)	4	90
5000 hours	-	-	61.0	(7400)	5	90

TRANSMISSIVITY AND TENSILE TESTING

MATERIAL: Polycarbonate

THICKNESS: 0.127 mm (5mil)

COATING: None

LAMINATED: No

ACCELERATING ENVIRONMENT: EMMAQUA Exposure

EXPOSURE TIME OR DOSAGE	YIELD STRENGTH MN/m^2	(psi)	BREAK STRENGTH MN/m^2	(psi)	ELONGATION PERCENT	TRANSMISSIVITY PERCENT	WEIGHT LOSS PERCENT
0	65.5	(9500)	68.3	(9900)	110	91	-
200,000 Langleys	64.8	(9400)	57.2	(8300)	32	83	+0.025

TRANSMISSIVITY AND TENSILE TESTING

MATERIAL: Polycarbonate
THICKNESS: 0.254 mm (10mil)
COATING: None
LAMINATED: No
ACCELERATING ENVIRONMENT: Thermal Aging, 120°C (248°F)

EXPOSURE TIME OR DOSAGE	YIELD STRENGTH MN/m^2	YIELD STRENGTH (psi)	BREAK STRENGTH MN/m^2	BREAK STRENGTH (psi)	ELONGATION PERCENT	TRANSMISSIVITY PERCENT
0	65.5	(9500)	68.3	(9900)	110	91
200 hours	82.1	(11900)	80.7	(11700)	99	90
500 hours	79.3	(11500)	79.3	(11500)	51	90
1000 hours	86.2	(12500)	73.8	(10700)	41	90
2000 hours	73.8	(10700)	73.8	(10700)	63	90

TRANSMISSIVITY AND TENSILE TESTING

MATERIAL: Polycarbonate

THICKNESS: 0.254 mm (10mil)

COATING: None

LAMINATED: No

ACCELERATING ENVIRONMENT: Thermal Aging, 150^{o}C (302^{o}F)

EXPOSURE TIME OR DOSAGE	YIELD STRENGTH MN/m^2	YIELD STRENGTH (psi)	BREAK STRENGTH MN/m^2	BREAK STRENGTH (psi)	ELONGATION PERCENT	TRANSMISSIVITY PERCENT
0	65.5	(9500)	68.3	(9900)	110	91
100 hours	66.9	(9700)	69.0	(10000)	67	90
200 hours	69.0	(10000)	68.3	(9900)	29	90
500 hours	57.2	(8300)	63.8	(7800)	9	90
1000 hours	69.0	(10000)	60.0	(8700)	31	90

TRANSMISSIVITY AND TENSILE TESTING

MATERIAL: Polycarbonate
THICKNESS: 0.127 mm (5mil)
COATING: None
LAMINATED: No
ACCELERATING ENVIRONMENT: Saturated Steam, $100^{o}C$ ($212^{o}F$)
EXTERNAL STRESS: 0 MN/m^2 (0 PSI)

EXPOSURE TIME OR DOSAGE	YIELD STRENGTH MN/m^2	(psi)	BREAK STRENGTH MN/m^2	(psi)	ELONGATION PERCENT	TRANSMISSIVITY PERCENT
0	65.5	(9500)	68.3	(9900)	110	91
1 week			78.6	(11400)	4	88
2 weeks (failure)						

TENSILE TESTING

MATERIAL: Polysulfone

THICKNESS: 0.508 mm (20mil)

COATING: None

LAMINATED: No

ACCELERATING ENVIRONMENT: UV Aging

EXPOSURE TIME OR DOSAGE	BREAK STRENGTH MN/m^2	(psi)	ELONGATION PERCENT
0	76.1	(11030)	6
1800 hours	69.0	(10000)	6
2000 hours	69.0	(10000)	6

TENSILE TESTING

MATERIAL: Polysulfone

THICKNESS: 0.508 mm (20mil)

COATING: None

LAMINATED: No

ACCELERATING ENVIRONMENT: EMMAQUA Exposure

EXPOSURE TIME OR DOSAGE	BREAK STRENGTH MN/m^2	(psi)	ELONGATION PERCENT
0	76.1	(11030)	6
200,000 Langleys	67.6	(9800)	6
317,000 Longleys	69.0	(10000)	6
800,000 Langleys	67.9	(9850)	6

TENSILE TESTING

MATERIAL: Polysulfone

THICKNESS: 0.508 mm (20mil)

COATING: None

LAMINATED: No

ACCELERATING ENVIRONMENT: Thermal Aging, 150°C (302°F)

EXPOSURE TIME OR DOSAGE	BREAK STRENGTH MN/m^2	(psi)	ELONGATION PERCENT
0	76.1	(11030)	6
200 hours	37.9	(5500)	5
1000 hours	80.7	(11700)	5
2000 hours	77.2	(11200)	6

TENSILE TESTING

MATERIAL: Polysulfone

THICKNESS: 0.508 mm (20mil)

COATING: None

LAMINATED: No

ACCELERATING ENVIRONMENT: Thermal Aging, 200°C (392°F)

EXPOSURE TIME OR DOSAGE	BREAK STRENGTH MN/m^2	(psi)	ELONGATION PERCENT
0	76.1	(11030)	6
100 hours	77.2	(11200)	6
200 hours	63.4	(9200)	6
500 hours	63.4	(9200)	6
1000 hours	53.8	(7800)	5

TENSILE TESTING

MATERIAL:	Polysulfone
THICKNESS:	0.508 mm (20mil)
COATING:	None
LAMINATED:	No
ACCELERATING ENVIRONMENT:	Saturated Steam, 100°C (212°F)
EXTERNAL STRESS:	0 MN/m^2 (0 PSI)

EXPOSURE TIME OR DOSAGE	BREAK STRENGTH MN/m^2	(psi)	ELONGATION PERCENT
0	76.1	(11030)	6
1 week	37.9	(5500)	6
3 weeks	36.6	(5300)	6
8 weeks	38.6	(5600)	5
20 weeks	40.0	(5800)	6

TENSILE TESTING

MATERIAL: Polysulfone

THICKNESS: 0.508 mm (20mil)

COATING: None

LAMINATED: No

ACCELERATING ENVIRONMENT: Saturated Steam, $100^{o}C$ ($212^{o}F$)

EXTERNAL STRESS: $.69 MN/m^2$ (100 psi)

EXPOSURE TIME OR DOSAGE	BREAK STRENGTH MN/m^2	(psi)	ELONGATION PERCENT
0	76.1	(11030)	6
1 week	75.9	(11000)	6
8 weeks	75.9	(11000)	5
20 weeks	73.1	(10600)	5

TENSILE TESTING

MATERIAL: Polysulfone

THICKNESS: 0.508 mm (20mil)

COATING: None

LAMINATED: No

ACCELERATING ENVIRONMENT: Saturated Steam, $100^{o}C$ ($212^{o}F$)

EXTERNAL STRESS: $1.38 MN/m^2$, (200 psi)

EXPOSURE TIME OR DOSAGE	BREAK STRENGTH MN/m^2	(psi)	ELONGATION PERCENT
0	76.1	(11030)	6
1 week	77.2	(11200)	6
3 weeks	72.4	(10500)	6
8 weeks	79.3	(11500)	5
20 weeks	74.5	(10800)	5

TENSILE TESTING

MATERIAL:	Polysulfone
THICKNESS:	0.508 mm (20mil)
COATING:	None
LAMINATED:	No
ACCELERATING ENVIRONMENT:	Saturated Steam, 120°C (248°F)
EXTERNAL STRESS:	0 MN/m^2, (0 PSI)

EXPOSURE TIME OR DOSAGE	BREAK STRENGTH MN/m^2	(psi)	ELONGATION PERCENT
0	76.1	(11030)	6
1 week	76.6	(11100)	5
3 weeks	79.3	(11500)	6
8 weeks	78.6	(11400)	6

TENSILE TESTING

MATERIAL: Polysulfone

THICKNESS: 0.508 mm (20mil)

COATING: None

LAMINATED: No

ACCELERATING ENVIRONMENT: Saturated Steam, 120^{o}C (248^{o}F)

EXTERNAL STRESS: .69MN/m^2, (100 psi)

EXPOSURE TIME OR DOSAGE	BREAK STRENGTH MN/ m^2 (psi)	ELONGATION PERCENT
0	76.1 (11030)	6
1 week (failure)		

TENSILE TESTING

MATERIAL: Polysulfone

THICKNESS: 0.508 mm (20mil)

COATING: None

LAMINATED: No

ACCELERATING ENVIRONMENT: Saturated Steam, 120^{o}C (248^{o}F)

EXTERNAL STRESS: 1.38MN/m^2, (200 psi)

EXPOSURE TIME OR DOSAGE	BREAK STRENGTH MN/ m^2	(psi)	ELONGATION PRECENT
0	76.1	(11030)	6
1 week (failure)			

TENSILE TESTING

MATERIAL: Polysulfone

THICKNESS: 0.508 mm (20mil)

COATING: None

LAMINATED: No

ACCELERATING ENVIRONMENT: Chemical Testing, 75°C, (167°F)
100% Ethylene Glycol

EXPOSURE TIME OR DOSAGE	BREAK STRENGTH MN/m^2	(psi)	ELONGATION PERCENT
0	76.1	(11030)	6
1 week	80.7	(11700)	6
3 weeks	69.0	(10000)	6
8 weeks	75.2	(10900)	6
20 weeks	74.5	(10800)	6

TENSILE TESTING

MATERIAL:	Polysulfone
THICKNESS:	0.508 mm (20mil)
COATING:	None
LAMINATED:	No
ACCELERATING ENVIRONMENT:	Chemical Testing, $75^{o}C$, ($167^{o}F$) 50 ppm Cl^{-}

EXPOSURE TIME OR DOSAGE	BREAK STRENGTH MN/m^2	(psi)	ELONGATION PERCENT
0	76.1	(11030)	6
1 week	74.5	(10800)	6
3 weeks	66.9	(9700)	6
8 weeks	47.6	(6900)	5
20 weeks	71.7	(10400)	5

TENSILE TESTING

MATERIAL: Polysulfone

THICKNESS: 0.508 mm (20mil)

COATING: None

LAMINATED: No

ACCELERATING ENVIRONMENT: Chemical Testing, 75°C, (167°F)
25 ppm Cu^{++}

EXPOSURE TIME OR DOSAGE	BREAK STRENGTH MN/m^2	(psi)	ELONGATION PERCENT
0	76.1	(11030)	6
1 week	70.3	(10200)	6
3 weeks	71.7	(10400)	6
8 weeks	70.3	(10200)	6
20 weeks	75.2	(10900)	5

TENSILE TESTING

MATERIAL: Polyethersulfone

THICKNESS: 0.508 mm (20mil)

COATING: None

LAMINATED: No

ACCELERATING ENVIRONMENT: UV Aging

EXPOSURE TIME OR DOSAGE	YIELD STRENGTH MN/m^2	(psi)	BREAK STRENGTH MN/m^2	(psi)	ELONGATION PERCENT
0	83.4	(12100)	69.0	(10000)	90
1000 hours	82.8	(12000)	62.1	(9000)	26

TENSILE TESTING

MATERIAL: Polyethersulfone

THICKNESS: 0.508 mm (20mil)

COATING: None

LAMINATED: No

ACCELERATING ENVIRONMENT: EMMAQUA Exposure

EXPOSURE TIME OR DOSAGE	YIELD STRENGTH MN/m^2	(psi)	BREAK STRENGTH MN/m^2	(psi)	ELONGATION PERCENT
0	83.4	(12100)	69.0	(10000)	90
400,000 Langleys	89.7	(13000)	62.1	(9000)	38

TENSILE TESTING

MATERIAL: Polyethersulfone

THICKNESS: 0.508 mm (20mil)

COATING: None

LAMINATED: No

ACCELERATING ENVIRONMENT: Thermal Aging, 150°C, (302°F)

EXPOSURE TIME OR DOSAGE	YIELD STRENGTH MN/m^2	YIELD STRENGTH (psi)	BREAK STRENGTH MN/m^2	BREAK STRENGTH (psi)	ELONGATION PERCENT
0	83.4	(12100)	69.0	(10000)	90
1000 hours	92.4	(13400)	64.1	(9300)	20

TENSILE TESTING

MATERIAL: Polyethersulfone

THICKNESS: 0.508 mm (20mil)

COATING: None

LAMINATED: No

ACCELERATING ENVIRONMENT: Thermal Aging, 200°C (392°F)

EXPOSURE TIME OR DOSAGE	YIELD STRENGTH MN/m^2	(psi)	BREAK STRENGTH MN/m^2	(psi)	ELONGATION PERCENT
0	83.4	(12100)	69.0	(10000)	90
100 hours	103.4	(15000)	69.0	(10000)	16
200 hours	103.4	(15000)	82.8	(12000)	10
500 hours	103.4	(15000)	82.8	(12000)	12
1000 hours	96.6	(14000)	75.9	(11000)	14

TENSILE TESTING

MATERIAL: Polyethersulfone

THICKNESS: 0.508 mm (20mil)

COATING: None

LAMINATED: No

ACCELERATING ENVIRONMENT: Saturated Steam, $100^{o}C$ ($212^{o}F$)

EXTERNAL STRESS: $1.38 MN/m^2$, (200 PSI)

EXPOSURE TIME OR DOSAGE	YIELD STRENGTH MN/m^2	YIELD STRENGTH (psi)	BREAK STRENGTH MN/m^2	BREAK STRENGTH (psi)	ELONGATION PERCENT
0	82.8	(12000)	69.0	(10000)	90
1 week	-	-	92.4	(13400)	7
3 weeks	-	-	82.8	(12000)	5
8 weeks	-	-	75.9	(11000)	5

TENSILE TESTING

MATERIAL: Polyethersulfone

THICKNESS: 0.508 mm (20mil)

COATING: None

LAMINATED: No

ACCELERATING ENVIRONMENT: Saturated Steam, 120°C (248°F)

EXTERNAL STRESS: 1.38MN/m^2,(200 PSI)

EXPOSURE TIME OR DOSAGE	YIELD STRENGTH MN/ m^2	(psi)	BREAK STRENGTH MN/m^2	(psi)	ELONGATION PERCENT
0	82.8	(12000)	69.0	(10000)	90
1 week	-	-	94.5	(13700)	7
3 weeks	-	-	96.6	(14000)	7
8 weeks	-	-	104.1	(15100)	7

TENSILE TESTING

MATERIAL: Polyethersulfone

THICKNESS: 0.508 mm (20mil)

COATING: None

LAMINATED: No

ACCELERATING ENVIRONMENT: Chemical Testing, 75°C (167°F)
100% Ethylene Glycol

EXPOSURE TIME OR DOSAGE	YIELD STRENGTH MN/m^2	(psi)	BREAK STRENGTH MN/m^2	(psi)	ELONGATION PERCENT
0	83.4	(12100)	69.0	(10000)	90
1 week	89.7	(13000)	66.2	(9600)	49
3 weeks	93.1	(13500)	67.7	(9800)	56
8 weeks	89.7	(13000)	62.8	(9100)	47

TENSILE TESTING

MATERIAL: Polyethersulfone

THICKNESS: 0.508 mm (20mil)

COATING: None

LAMINATED: No

ACCELERATING ENVIRONMENT: Chemical Testing, 75^{o}C (167^{o}F)
25 ppm Cu^{++}

EXPOSURE TIME OR DOSAGE	YIELD STRENGTH MN/m^2	(psi)	BREAK STRENGTH MN/m^2	(psi)	ELONGATION PERCENT
0	83.4	(12100)	69.0	(10000)	90
1 week	89.7	(13000)	62.1	(9000)	73
3 weeks	89.7	(13000)	66.2	(9600)	39
8 weeks	89.7	(13000)	65.5	(9500)	27

TENSILE TESTING

MATERIAL: Polyethersulfone

THICKNESS: 0.508 mm (20mil)

COATING: None

LAMINATED: No

ACCELERATING ENVIRONMENT: Chemical Testing, 75°C (167°F)
50 ppm Cl^-

EXPOSURE TIME OR DOSAGE	YIELD STRENGTH MN/m^2	YIELD STRENGTH (psi)	BREAK STRENGTH MN/m^2	BREAK STRENGTH (psi)	ELONGATION PERCENT
0	83.4	(12100)	69.0	(10000)	90
1 week	89.7	(13000)	62.1	(9000)	72
3 weeks	93.8	(13600)	66.2	(9600)	20
8 weeks	100.0	(14500)	66.2	(9600)	49

TRANSMISSIVITY AND TENSILE TESTING

MATERIAL: Polyarylate

THICKNESS: 0.127 mm (5mil)

COATING: None

LAMINATED: No

ACCELERATING ENVIRONMENT: UV Aging

EXPOSURE TIME OR DOSAGE	YIELD STRENGTH MN/m^2	(psi)	BREAK STRENGTH MN/m^2	(psi)	ELONGATION PERCENT	TRANSMISSIVITY PERCENT
0	77.9	(11300)	77.9	(11300)	50	89
2000 hours	75.9	(11000)	71.7	(10400)	32	89
4000 hours	82.8	(12000)	78.6	(11400)	40	90

TRANSMISSIVITY AND TENSILE TESTING

MATERIAL: Polyarylate

THICKNESS: 0.127 mm (5mil)

COATING: None

LAMINATED: No

ACCELERATING ENVIRONMENT: EMMAQUA Exposure

EXPOSURE TIME OR DOSAGE	YIELD STRENGTH MN/m^2	YIELD STRENGTH (psi)	BREAK STRENGTH MN/m^2	BREAK STRENGTH (psi)	ELONGATION PERCENT	TRANSMISSIVITY PERCENT	WEIGHT LOSS PERCENT
0	77.9	(11300)	77.9	(11300)	50	89	0
200,000 Langleys	85.5	(12400)	77.9	(11300)	13	85	-2.8
400,000 Langleys	75.9	(11000)	69.0	(10000)	9	85	-5.8

TRANSMISSIVITY AND TENSILE TESTING

MATERIAL: Polycarbonate

THICKNESS: 0.254 mm (10mil)

COATING: See below

LAMINATED: With Polysulfone

ACCELERATING ENVIRONMENT: UV Aging

EXPOSURE TIME OR DOSAGE	YIELD STRENGTH MN/m^2	(psi)	BREAK STRENGTH MN/m^2	(psi)	ELONGATION PERCENT	TRANSMISSIVITY PERCENT
0	65.5	(9500)	68.3	(9900)	110	91
2000 hours	-	-	58.6	(8500)	5	90
4000 hours	-	-	56.6	(8200)	4	90
4000 hours (See Note 1)	61.4	(8900)	58.6	(8500)	6	90
4000 hours (See Note 2)	-	-	66.9	(9700)	5	90

Notes: 1. Coated with KL-1-1063
2. Coated with LS-123

TRANSMISSIVITY AND TENSILE TESTING

MATERIAL: Polycarbonate

THICKNESS: 0.254 mm (10mil)

COATING: See below

LAMINATED: With Polysulfone

ACCELERATING ENVIRONMENT: EMMAQUA Exposure

EXPOSURE TIME OR DOSAGE	YIELD STRENGTH MN/m^2	YIELD STRENGTH (psi)	BREAK STRENGTH MN/m^2	BREAK STRENGTH (psi)	ELONGATION PERCENT	TRANSMISSIVITY PERCENT	WEIGHT LOSS PERCENT
0	65.5	(9500)	68.3	(9900)	110	91	0
200,000 Langleys	-	-	55.0	(7980)	1	89	-0.025
400,000 Langleys	-	-	31.0	(4500)	3	64	-11.38
400,000 Langleys (See Note 1)	80.0	(11600)	65.5	(9500)	46	89	-2.75
400,000 Langleys (See Note 2)	-	-	71.0	(10300)	5	81	-3.39

Notes: 1. Coated with KL-1-1063
2. Coated with LS-123

TENSILE TESTING

MATERIAL: Polysulfone

THICKNESS: 0.508 mm (20mil)

COATING: See below

LAMINATED: With Polycarbonate

ACCELERATING ENVIRONMENT: UV Aging

EXPOSURE TIME OR DOSAGE	BREAK STRENGTH MN/m^2	(psi)	ELONGATION PERCENT
0	76.1	(11030)	6
2000 hours	75.9	(11000)	6
4000 hours	69.0	(10000)	6
4000 hours (See Note 1)	69.0	(10000)	6
4000 hours (See Note 2)	73.1	(10600)	6

Notes: 1. Polycarbonate coated with KL-1-1063.
2. Polycarbonate coated with LS-123.

TENSILE TESTING

MATERIAL: Polysulfone

THICKNESS: 0.508 mm (20mil)

COATING: See below

LAMINATED: With Polycarbonate

ACCELERATING ENVIRONMENT: EMMAQUA Exposure

EXPOSURE TIME OR DOSAGE	BREAK STRENGTH MN/m^2	(psi)	ELONGATION PERCENT
0	76.1	(11030)	6
200,000 Langleys	71.7	(10400)	6
400,000 Langleys	70.3	(10200)	6
400,000 Langleys (See Note 1)	71.0	(10300)	6
400,000 Langleys (See Note 2)	71.0	(10300)	5

Notes: 1. Polycarbonate coated with KL-1-1063.
2. Polycarbonate coated with LS-123.

TRANSMISSIVITY AND TENSILE TESTING

MATERIAL: Polyarylate
THICKNESS: 0.127 mm (5mil)
COATING: None
LAMINATED: With Polyethersulfone
ACCELERATING ENVIRONMENT: EMMAQUA Exposure

EXPOSURE TIME OR DOSAGE	YIELD STRENGTH MN/m^2	(psi)	BREAK STRENGTH MN/m^2	(psi)	ELONGATION PERCENT	TRANSMISSIVITY PERCENT	WEIGHT LOSS PERCENT
0	77.9	(11300)	77.9	(11300)	50	89	0
200,000 Langleys	85.5	(12400)	77.9	(11300)	13	85	-
400,000 Langleys	75.9	(11000)	71.7	(10400)	10	86	-6.5

TENSILE TESTING

MATERIAL: Polyethersulfone

THICKNESS: 0.508 mm (20mil)

COATING: None

LAMINATED: With Polyarylate

ACCELERATING ENVIRONMENT: EMMAQUA Exposure

EXPOSURE TIME OR DOSAGE	YIELD STRENGTH MN/m^2	(psi)	BREAK STRENGTH MN/m^2	(psi)	ELONGATION PERCENT
0	83.4	(12100)	69.0	(10000)	90
400,000 Langleys	91.7	(13300)	64.8	(9400)	20

U. V. SCREENING OF COATINGS

EXHIBIT C

FIGURES 1 THROUGH 5

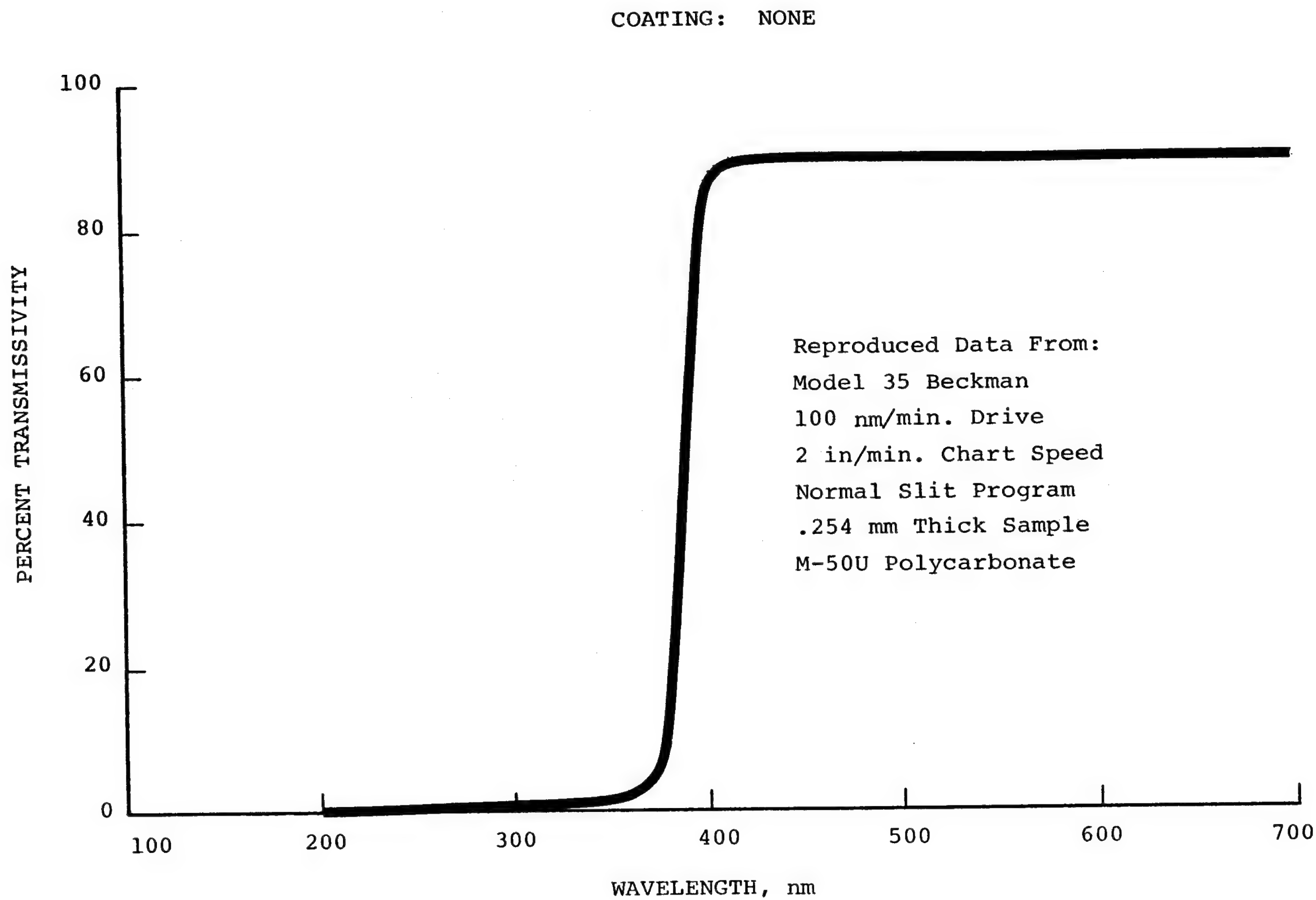

COATING: NONE
100
80
60
40
20
0
PERCENT TRANSMISSIVITY
Reproduced Data From:
Model 35 Beckman
100 nm/min. Drive
2 in/min. Chart Speed
Normal Slit Program
.254 mm Thick Sample
M-50U Polycarbonate
100
200
300
400
500
600
700
WAVELENGTH, nm

FIGURE 1

COATING: LS-123

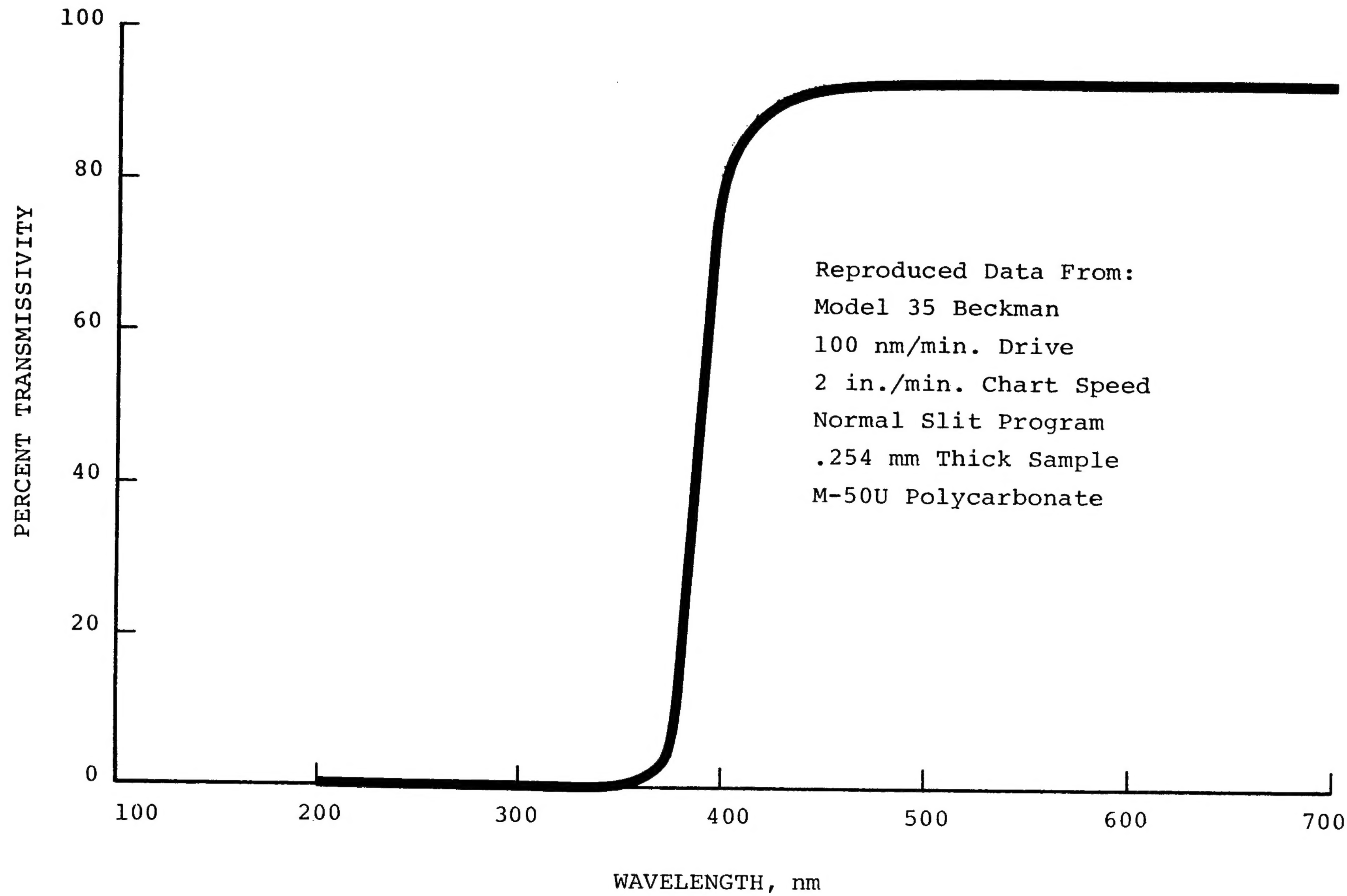


FIGURE 2

COATING: J797

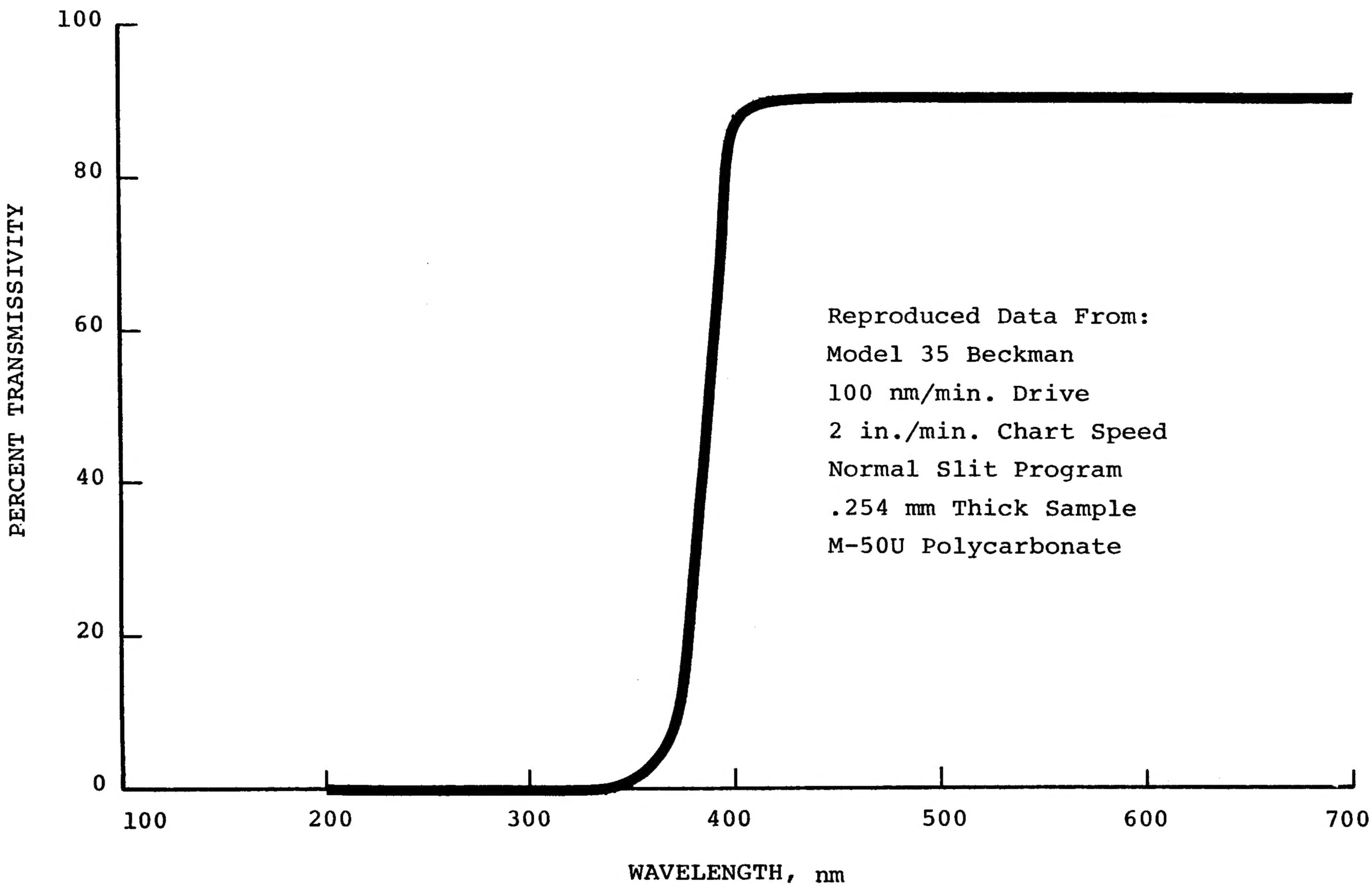


FIGURE 3

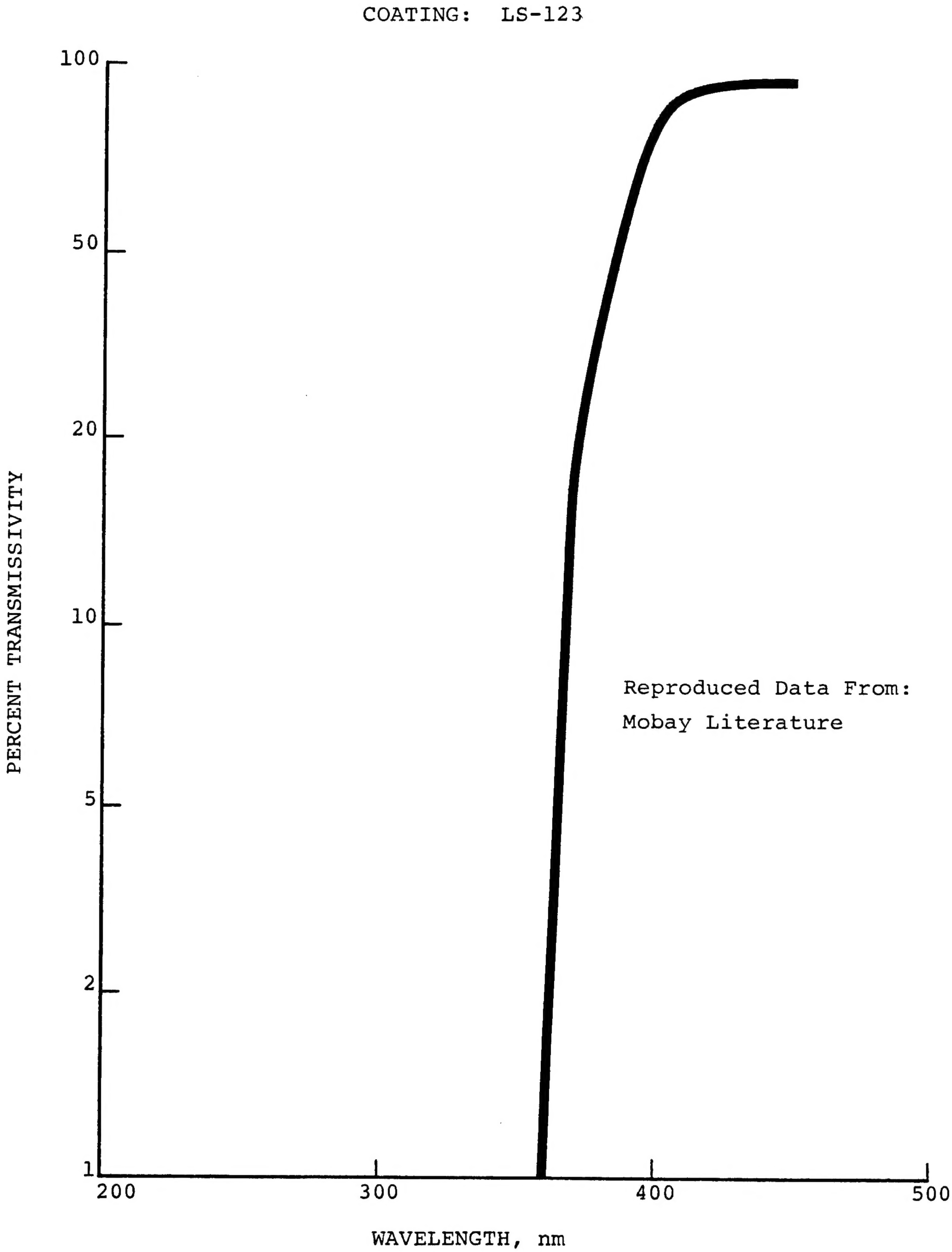

COATING: LS-123
100
50
20
10
5
2
1
PERCENT TRANSMISSIVITY
Reproduced Data From:
Mobay Literature
200
300
400
500
WAVELENGTH, nm

FIGURE 4

COATING: KL-1-1063

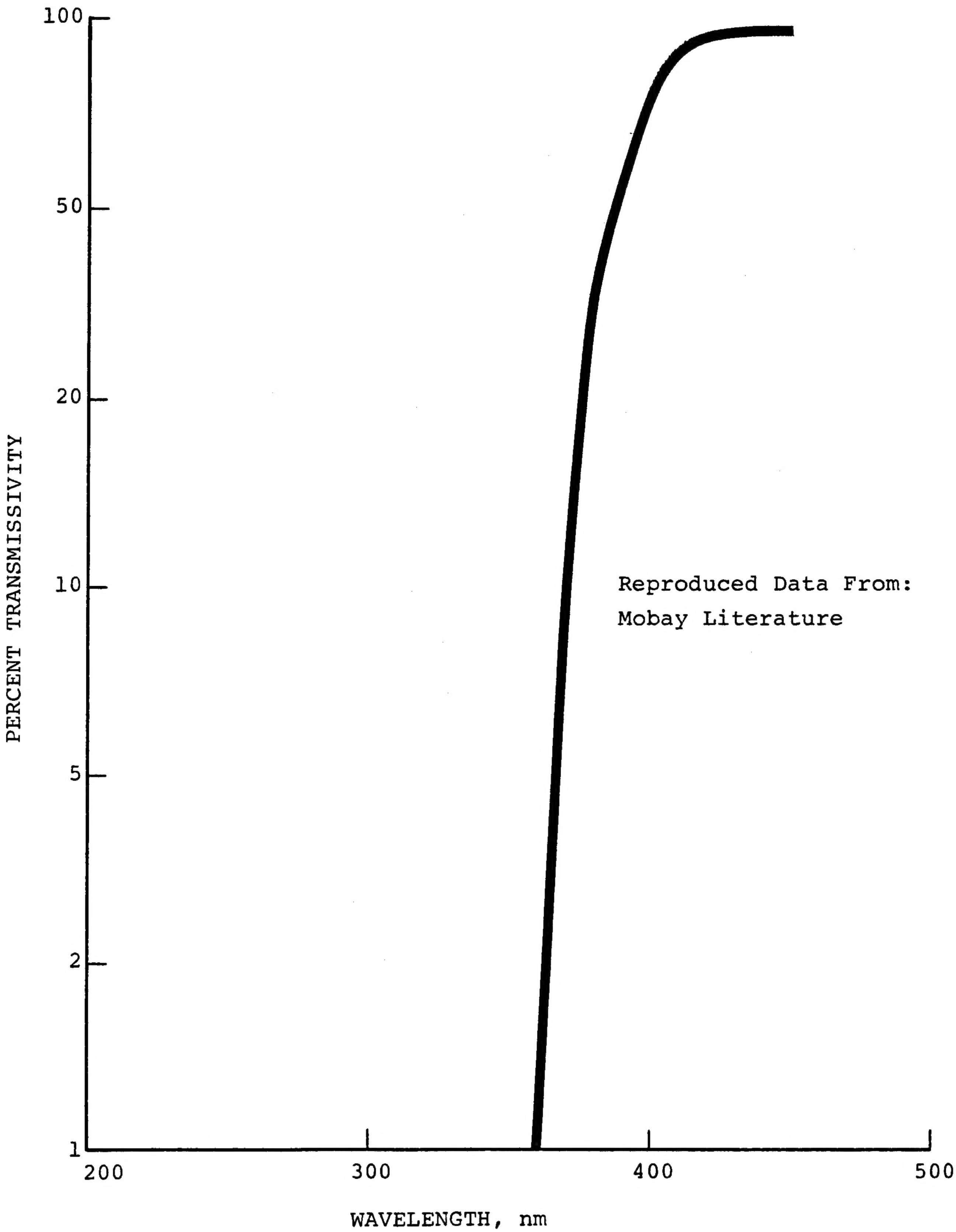


FIGURE 5

☆U.S. GOVERNMENT PRINTING OFFICE: 1980-740-145/661